

July
2020

Distillation: Controlling Reboilers

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Reducing
Emissions
With Seals

Crystallization

Facts at Your
Fingertips:
Cyclone
Separators

Focus on
Temperature

Owning Your
Career

July 2020

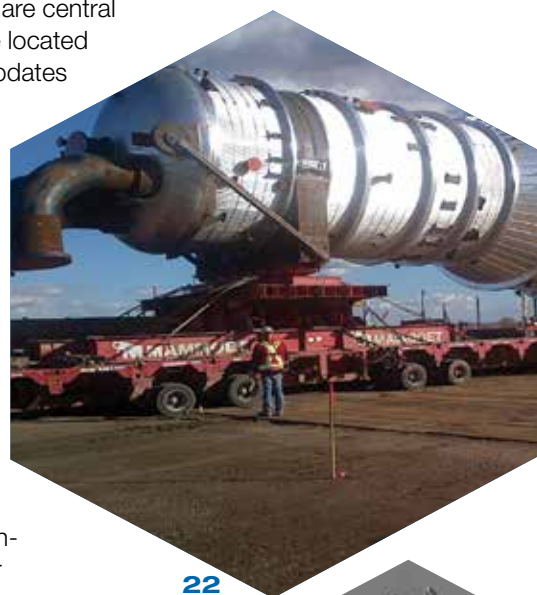
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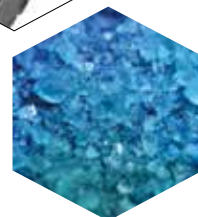
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Editor's Page

Awarding 'green chemistry'

One important challenge that continues to receive the attention of scientists and engineers worldwide is the creation of a more sustainable environment. The U.S. Environmental Protection Agency (EPA; www.epa.gov) recognizes achievements in this area through the Green Chemistry Challenge Awards, which "promote the environmental and economic benefits of developing and using novel green chemistry."

Last month, the 2020 recipients of these awards were announced. Details about the award and selection criteria can be found on the EPA's website. The five winners of the 2020 Green Chemistry Challenge Awards are described here (Source: EPA).

Greener Reaction Conditions Award — Merck & Co. (Rahway, N.J.; www.merck.com) was recognized for improving the process used to produce certain antiviral drugs. The existing synthesis processes were inefficient due to poor chemoselectivity and the need for multiple reaction steps that involved expensive and hazardous reagents. Merck developed a catalyst that reduced the process to two reaction steps with a high purity yield. The new process is said to improve manufacturing efficiency and sustainability of one antiviral drug by more than 85%, with improvements in energy use, water depletion and other metrics.

Greener Synthetic Pathways Award — Genomatica (San Diego, Calif.; www.genomatica.com) received this award for developing a new brand of 1,3-butylene glycol — which is used in cosmetics — via a one-step fermentation process that uses renewable sugar feedstock and engineered *E. coli*. Genomatica's process replaces the traditional fossil-fuel-based production route that uses acetaldehyde and heavy metals, thereby reducing greenhouse-gas emissions and eliminating the use of more hazardous materials. The company has already produced the butylene glycol at commercial scale.

Designing Greener Chemicals Award — Johns Manville, a Berkshire Hathaway Company (Littleton, Colo.; www.jm.com) was recognized for developing a thermoset binder for fiberglass reinforcement that is approximately 90% biobased, and free from formaldehyde. The process uses renewable carbohydrates produced from corn, potato or wheat starch. In addition to eliminating formaldehyde, the new technology uses water and energy more efficiently and produces a product with performance advantages.

Academic Award — Recognition was given to professor Steven Skerlos, from the University of Michigan and Fusion Coolant Systems (Canton, Mich.; www.fusioncoolant.com) for developing a technology that uses supercritical CO₂ for metalworking in place of traditional oil-based metalworking fluids. The traditional fluids can be difficult to treat after use, because they may contain hazardous additives, or heavy metals that may be picked up during the metalworking itself. The new technology developed at the University of Michigan, and being commercialized by Fusion Coolant Systems, uses little to no oil lubricant.

Small Business Award — Vestaron Corp. (Kalamazoo, Mich.; www.vestaron.com) received this award for the development of a new biopesticide that controls targeted pests with no adverse effects on the environment, people and wildlife. The novel insecticide is based on a peptide that is found in a spider's venom. The peptide is produced by yeast fermentation using sugar derived from corn.



Dorothy Lozowski, Editorial Director

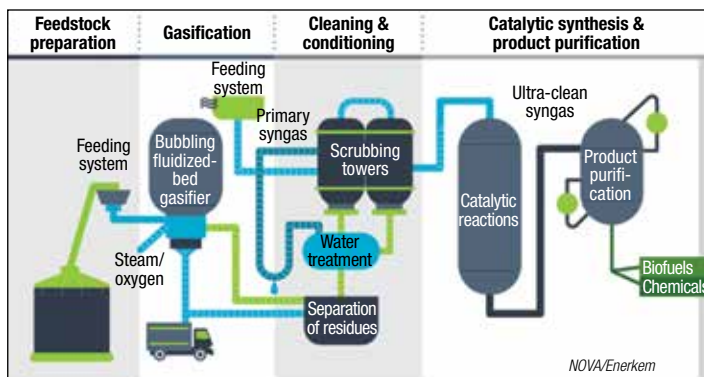
JDA to advance conversion of syngas to ethylene

A recently announced joint development agreement (JDA) between Enkern Inc. (Montreal, Que.; www.enkern.com) and NOVA Chemicals (Calgary, Alta.; www.novachem.com) is aimed at developing recycling technology to allow difficult-to-recycle plastics (specifically #3–7 polymers), as well as other municipal solid waste (MSW), household waste and construction materials, to be converted into ethylene at full commercial scale.

The development project will involve Enkern's gasification process, which is capable of generating synthesis gas (syngas; CO and H₂) from a wide range of feedstocks, including MSW, biomass and polymers, including polyvinyl chloride (PVC) and polyethylene terephthalate (PET). Enkern's gasification platform involves gasification of sorted feedstocks by thermal cracking in a bubbling, fluidized-bed gasifier, followed by purifying and separating the syngas (diagram). Currently Enkern converts syngas to methanol and ethanol.

"By advancing recycling technology to transform syngas to ethylene, we aim to create a plastics circular economy that lowers the energy intensity and cost of the process compared to other routes, such as ethylene via syngas and ethanol," says Sarah Marshall, director of sustainability at NOVA Chemicals. "A vital parameter is the carbon

efficiency — the percentage of carbon in the plastic waste that is turned into useful product (preferably ethylene)," added Peter Nieuwenhuizen, Enkern's vice president of



technology strategy and deployment."

The research will be conducted at existing facilities — NOVA Chemicals' research will be conducted from the Centre for Applied Research in Calgary, while Enkern will be working at its facility in Edmonton, Alberta, with further expertise coming from its team in Westbury, Quebec. Pilot equipment is foreseen to be built in in Edmonton, NOVA Chemicals says, making use of Enkern's next-door Edmonton Alberta Biofuels (EAB) facility, which produces syngas from waste, to make biofuels.

"Project success relies not only on finding a technical pathway from syngas to ethylene, but also on achieving the economics to successfully scale the technology," NOVA's Marshall says.

Edited by:
Gerald Ondrey

ISONONYL ALCOHOL

Last month, Dow, Inc. (Midland, Mich.; www.dow.com) and Johnson Matthey (London, U.K.; www.matthey.com) announced that Zibo Qixiang Tengda Chemical Ltd. (QXTD; Linzi district, China; en.qxtgdg.com), has selected LP Oxo Technology to produce isononyl alcohol (INA) at its new manufacturing facility. The plant will be built at QXTD's integrated petrochemical complex in Zibo City, China and will produce 200,000 metric tons per year (m.t./yr) of INA. The plant operation is expected to come online in 2023.

"QXTD will be the first in the industry to take advantage of our process technology for more sustainable INA production," says Donna Babcock, global business director for Industrial Solutions, a business segment of Dow. "This technology requires a smaller manufacturing footprint and less energy consumption compared to typical INA production processes, without a loss in efficiency and throughput."

INA is often used to make plasticizers of diisononyl phthalate, diisononyl adipate and triisononyl trimellitate, which are mainly used in the polyvinylchloride industry.

ACRYLIC ACID

Last month, Celanese Corp. (Dallas, Tex.; www.celanese.com) announced that its subsidiary, Celanese (Nanjing) Chemical Co., has recently signed a tri-party agreement with Southwest Institute of Chemical Ltd. (SW-CHEM; Chengdu, China) and YankuangLunan Chemical Co. (Lunan; Teng Zhou, China), to build a pilot scaleup unit (PSU) in Teng Zhou, China, to test industrial-scale production of acrylic acid using acetic acid

Na-ion battery design eliminates crystal formation

Researchers at Washington State University (Pullman, Wash.; www.wsu.edu) and Pacific Northwest National Laboratory (Richland, Wash.; www.pnnl.gov) have created a cathode material and electrolyte system for sodium-ion batteries that overcomes limitations observed with previous approaches to Na-ion batteries. Na-ion batteries are being explored as possible alternatives to now-ubiquitous lithium-ion batteries because they use cheaper, more abundant starting materials.

Cathodes made from layered sodium and transition-metal oxides (O3-type layered materials) are promising materials for high-performance Na-ion batteries, but they form a non-reactive layer of sodium salt crystals at the cathode surface with repeated re-

charging. This salt buildup stops the flow of sodium ions and renders the battery inoperable. The PNNL and WSU researchers developed an advanced liquid electrolyte that includes extra sodium ions to improve the interaction between electrolyte and cathode. The design for the cathode and electrolyte suppresses the formation of the inactive surface crystals and allows continued movement of sodium ions.

With the new electrolyte, the layered cathode can deliver a specific capacity of about 196 mAh/g and demonstrates more than 80% capacity retention over 1,000 cycles, the researchers say. The research team is working to better understand the electrolyte-cathode interaction and trying to eliminate the need for cobalt in the battery cathode design.

(Continues on p. 6)

as the principal raw material.

Celanese and SWCHEM are jointly developing a technology for producing acrylic acid by the condensation of acetic acid formaldehyde, which is based on Celanese's original proprietary research in this field. Under the terms of the agreement, Lunan will build an industrial-scale pilot plant to finish commercial production trials.

POWER-TO-LIQUIDS

European industry consortium Norsk e-Fuel AS (Oslo; www.norsk-e-fuel.com) plans to industrialize power-to-liquid technology (PTL) in Norway for the European market. The new project will allow the conversion of Norway's extensive renewable electricity resources into renewable fuels.

The joint venture (JV) is composed of four partners: Sunfire GmbH (Dresden, Germany), Climeworks AG (Zurich, Switzerland), Paul Wurth S.A. (Luxembourg), and the green investment company Valinor AS (Stavanger, Norway), parent company of Norsk Vind, the largest private wind-power developer in Norway.

In the project, synthesis gas (syngas; H_2 and CO) will be produced from renewable electricity, water and CO_2 using Sunfire's single-step co-electrolysis process and Climework's direct-air capture technology. Renewable fuels, such as jet fuel, are then produced through further processing and refining. The certified end products can be used directly in existing infrastructures.

The first plant, to be located at Herøya Industry Park in Porsgrunn, will have a production capacity of 10 million L/yr when it starts up in 2023. This plant will be upscaled 10-fold to produce 100 million L/yr of renewable fuel before 2026.

GAS TREATMENT

BASF SE (Ludwigshafen, Germany; www.basf.com) and ExxonMobil Catalysts and Licensing LLC (Houston; www.exxonmobilchemical.com) have introduced a new, highly energy-efficient amine gas-treatment technology, named OASE sulfexx, which is based on a proprietary amine-based

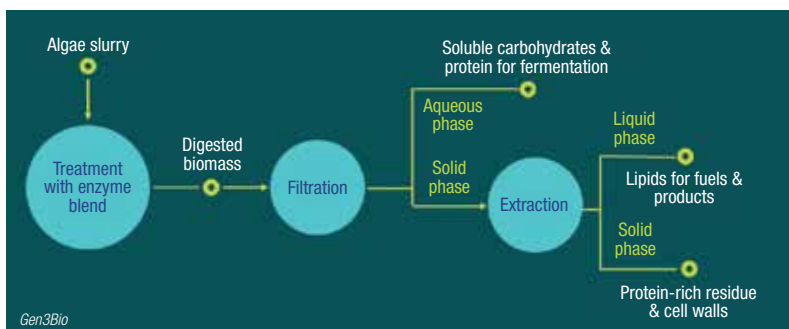
Enzymatic conversion of waste algae into specialty chemicals

Waste algae from municipal wastewater-treatment plants is typically sent to landfills, but a new process offered by Gen3Bio, Inc. (West Lafayette, Ind.; www.gen3bio.com) aims to convert it into specialty chemicals using a proprietary blend of enzymes to break open — but not digest — the microalgae. "This releases the internal lipids, proteins and carbohydrates to provide a filtrate containing monosaccharides and soluble proteins and a precipitate with lipids, insoluble proteins and algal cell walls," explains CEO Kelvin T. Okamoto.

As an alternative to landfilling, waste algae streams are sometimes processed via hydrothermal liquefaction, but this process involves much higher operating costs when compared to Gen3Bio's method, continues Okamoto. "The process is greater than 90% efficient in lipid, protein and carbohydrate recovery, thus allowing for several specialty-chemical revenue streams to be produced from the algae," he says. The starting algae strain or strain mix will determine the ratio and type of end specialty chemicals that can be produced, and the process can

handle most algae strains that do not have a thick cell wall. "The filtrate can be fermented to produce ethanol, succinic acid, itaconic acid or any other byproduct of fermentation. Succinic acid is the first target for fermentation due to a large global demand for biosuccinic acid that is not presently being met," explains Okamoto. The precipitate can be further separated into lipids (to produce biodiesel, omega-3 fatty acids or glycerol), proteins (which can be hydrolyzed to produce peptides and amino acids) and algal cell walls (which can yield glycolipids, glycans and phospholipids).

So far, the enzymatic process has been demonstrated in a 55-L mobile plant, and recent funding awards will allow the process to be further developed at a wastewater-treatment plant in Roberts, Wisconsin this summer in association with Clearas Water Recovery, Inc. (Missoula, Mont.; www.clearaswater.com).



FOG separation technology expands to new application areas

Fats, oil and grease (FOG) waste can create environmental problems for water-treatment and sewage systems, but can be a potential resource if collected and separated efficiently. A technology originally developed by Downey Ridge Environmental Co. (Lansing, W.Va.; www.greasezilla.com) to separate FOG from water for disposal of grease-trap waste is now finding uses in other industry sectors, such as biodiesel production, food processing, anaerobic digestion and water reclamation. The thermal separation technology, known as Greasezilla, helps generate useful products and fuels from FOG waste.

The process begins by gravity separation of water and FOG-containing sludge. The sludge is then pumped into dual insulated tanks that are heated to a constant temperature of 160°F for 24 hours to thermally render the fats in the sludge and bring them out of solution. The heating sepa-

rates the tank contents into three distinct layers: brown grease, a mixture of mostly saturated triglycerides in the C16 to C18 range; pasteurized organic material; and residual water.

A portion (~5%) of the brown grease recovered from the system is used directly as fuel to power its own boiler, while the rest can be sold as a feedstock for making biodiesel, because of its low moisture level (<1%).

The FOG separation system is being used upstream of municipal water treatment facilities, as well as by biodiesel producers, who can generate their own feedstock by processing FOG waste that waste haulers pay to unload, explains company president Ron Crosier. Large food-processing facilities are now beginning to use the modular system to process their own FOG waste, rather than paying for disposal. In addition, the pasteurized sludge layer is used in anaerobic digesters to generate biogas.

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Improved catalyst production lowers electrolysis costs

Water electrolysis is widely used for hydrogen production, but there are still high costs associated with manufacturing advanced electrolysis catalysts, which may involve high temperatures and pressures or chemical vapor deposition. Extending research conducted at the University of Kansas' Bioscience & Technology Business Center (Lawrence, Kan.; www.btbcku.com), startup company Avium, LLC (www.aviumenergy.com) has developed a new technology that promises to simplify the manufacture of high-performance catalysts for alkaline electrolysis systems.

Avium's patented synthesis method uses water as its only solvent, and the only energy input is for a microwave heating step, which produces a highly active dual-element matrix (DEM) catalyst structure, explains Joseph Barforoush, Avium chief technology officer. Whereas conventional catalysts depend on precious metals, such as platinum or iridium, Avium's DEM catalysts utilize pairs of abundant metals, such as nickel and iron. The microwave-synthesis method enables homogenous dispersion of

the metals, which helps to maximize the number of active sites in the DEM. "The key to improving catalyst efficiency is that the two elements in the DEM produce a synergistic effect, resulting in faster kinetics than catalysts composed of either single metal alone," adds Barforoush.

Alkaline electrolysis systems are typically limited in their production capacities when compared to proton-exchange-membrane electrolysis systems, but Avium is working to close this gap while also lowering costs. With funding from the U.S. National Science Foundation, the company is developing a commercial-scale DEM alkaline electrolyzer that can reportedly operate at 2–4 times the production rate of conventional alkaline electrolyzers operating at the same voltage. To achieve this, Avium and KU are working to synthesize its catalysts and fabricate electrodes at an industrial scale, while also continuing ongoing work related to electrode architecture and kinetics. The final goal will be to produce a DEM electrolyzer with a 4-kg/d capacity, which will be demonstrated at a hydrogen refueling station in California.

solvent that selectively removes H_2S , while minimizing the co-absorption of CO_2 from gas streams.

The companies jointly developed the amine-based solvent to help petroleum refiners and gas processors meet future requirements, while also increasing capacity and lowering operating costs on existing equipment. For new facilities, the use of this technology will reduce the size of the equipment and the initial capital investment compared to conventional amine-gas-treatment units, the companies say.

Multiple pilot-plant tests at ExxonMobil and BASF facilities have demonstrated the superior selective properties of this solvent compared to methyldiethanolamine (MDEA) formulations and Flexsorb SE and SE Plus solvents. A commercial demonstration concluded at a tailgas-treating unit located in North America further confirmed the results. OASE sul-

(Continues on p. 8)

fexx will help to debottleneck existing Claus tailgas treating, acid gas enrichment, and high-pressure acid-gas-removal units. In Claus tailgas-treating units, the technology can achieve less than 10 parts per million by volume (ppmv) H₂S specifications while rejecting CO₂ to meet future emission requirements.

VANILLIN FROM WOOD

Researchers from the Johannes Gutenberg University Mainz (JGU; Germany; www.uni-mainz.de) have developed a sustainable, electrolytic-depolymerization process for extracting the flavoring agent vanillin from lignin, a component of wood. Large quantities of waste lignin accumulate during the production of pulp for papermaking. The process, described in a recent issue of *ACS Sustainable Chemistry & Engineering*, involves dissolving the lignin in caustic soda and heating this mixture to 160°C in a simple electrolysis cell with nickel electrodes to which a current is applied. This oxidizes and breaks down the lignin to produce vanillin of such a high quality in a reagent-less process that it can be officially declared natural vanillin.

Up to now, vanillin has been predominantly made from petroleum, a process which, in contrast to this new method, produces toxic waste that is difficult to dispose of.

As part of the E.U.-funded Liberate project, the method, which has so far only been used in the laboratory, will soon be tested on an industrial scale. A pilot plant is currently being built at the Norwegian research institute Sintef, with which JGU is cooperating. The next step is to determine if the new method produces vanillin not only from pure lignin, but directly from the so-called black liquor.

PDH CATALYST

A team of scientists from Hokkaido University (Japan; www.general.hokkaidai.ac.jp) has developed an ultrastable, selective catalyst for propane dehydrogenation (PDH). The

Pilot plant produces apatite from mine waste

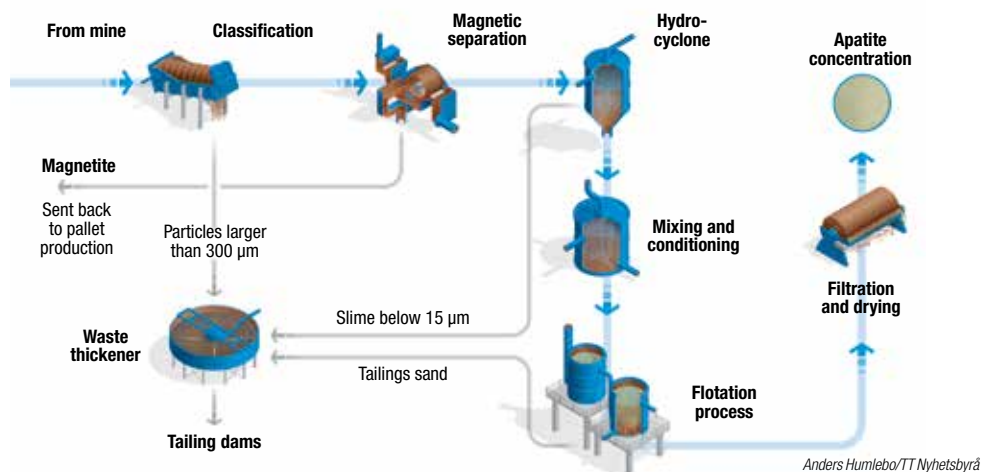
In a project called ReeMAP, LKAB Minerals AB (Luleå, Sweden; www.lkabminerals.com) is developing technology to recycle mine waste to produce phosphorus mineral fertilizers, rare earth elements (REEs), fluorine and gypsum. The first step is to use the mine waste to produce an apatite concentrate, something LKAB is now doing in its pilot plant.

The pilot plant is built on container plat-

form the non-valuable tailings. This process is repeated in several steps to obtain a high-purity product with the right specification for further processing.

Further processing will be done using innovative chemical processing, which LKAB is developing. Here, the apatite will be processed into monoammonium phosphate (MAP) fertilizers, REEs, fluorine and gypsum.

"We estimate that full-scale production



forms to allow it to be moved within and between LKAB's production plants in Malmberget and Kiruna, in Northern Sweden. Tests with tailings sand (waste material that is a byproduct of mining) from the two mines and the respective processing plants will be carried out in campaigns. Right now, a production campaign is underway in Malmberget. The process has multiple steps (diagram), with flotation the key principle applied to separate the apatite

from Malmberget and Kiruna will produce around 400,000 metric tons of apatite concentrate annually, in two plants that will be of similar size to our existing iron-ore concentrating plants," says Leif Boström, senior vice president for Business Area Special Products and CEO of LKAB Minerals. How soon that will be depends on the technical developments and the pre-engineering, but also on external factors, such as environmental permits, Boström says.

Producing hydrogen (and more) from biomass

A new electrochemical system that uses biomass-derived lignin to produce hydrogen has been developed by a team from the School of Energy and Chemical Engineering at the Ulsan National Institute of Science and Technology (Ulsan, South Korea; www.unist.ac.kr), led by professor Jungki Ryu.

In conventional technology, hydrogen is produced through the electrolysis of water. However, in this technology, the oxygen-generation reaction is slow and the hydrogen production is inefficient. This is because the electrons that produce the hydrogen come from the oxygen-evolution reaction.

The team uses a molybdenum-based, inexpensive metal catalyst (phosphomo-

lybdc acid) to break down lignin at low temperatures, and extract the electrons to produce hydrogen. The new system moves electrons from lignin along a wire to the electrode where the hydrogen-evolution reaction occurs. This makes it possible to produce hydrogen with less energy than conventional water electrolysis, as there is no need for oxygen reactions. "Our work is also significant, as it presents a new way to replace oxygen-producing reactions in the electrolysis of water," says Ryu.

Conventional methods require more than 1.5 V, but the new system can produce hydrogen gas at 0.95 V. Additionally, carbon monoxide and vanillin, which are produced via lignin breakdown, are useful in several industrial processes.

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High-resolution 3D-printing makes small, structured parts

Manufacturing of centimeter-sized test specimens for material characterization according to ISO standards has now been achieved for the first time with a technology that allows 3D-printing a feature size of 200 nm. UpNano GmbH (Vienna, Austria; www.upnano.at) succeeded in printing test specimens from its specific photopolymer with its NanoOne-printer in sizes and shapes necessary for ISO tests. This achievement is the result of a productive collaboration with the Vienna University of Technology (www.tuwien.at). Previously, it was considered impossible to print specimens at the (large) size necessary for ISO tests with a photopolymer and a two-photon-polymerization (2PP) 3D-printer that at the same time is able to achieve a resolution in the sub-micrometer range, says the company.

The laser lithography system is capable of producing polymeric micro-scale parts and meso-scale components with micro-scale features and nanometer resolution. The system is based on 2PP, which is the key to the high resolution. Compared to laser systems

that are based on one-photon absorption, two-photon absorption has a much higher

spatial selectivity, because the probability of absorbing two photons is significantly reduced outside the focal point. This enables the system to print structures with dimensions from nano- to centimeter scale. Also, the company says it can print such structures 100 times faster than standard techniques.

The technology can be used for the production of micro-sized parts with a grid or other complex structures (photo); large porous structures; and even for printing living cells for in vitro cell testing, as well as scaffolds for living cells and sterile micro-fluidic elements. ■



catalyst has been shown to remain active, even at temperatures of more than 600°C. Reaction temperatures of more than 600°C are necessary to obtain sufficient propylene yields, but under these harsh conditions, severe catalyst deactivation is inevitable due to carbon deposition or sintering, or both. Catalysts in practical use, therefore, must be regenerated either continuously or in short cycles, making the process inefficient and costly.

The newly developed catalyst (PtGa-Pb/SiO₂), which is silica-supported and made by adding lead to the surface of the intermetallic, PtGa, exhibits no deactivation when dehydrogenating propane at 600°C. The catalyst maintained the initial conversion rate of 30% for 96 h after the reaction started, which is significantly more stable than conventional catalysts. A propylene selectivity of as high as 99.6% is achieved, with few side reactions, including carbon deposition. □

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Plant Watch

Repsol plans new synthetic fuels, pyrolysis plants in decarbonization push

June 16, 2020 — Repsol S.A. (Madrid, Spain) announced two decarbonization projects to be located in the Port of Bilbao, Spain. The first project, in which €60 million will initially be invested, involves building one of the largest net-zero-emissions synthetic-fuel production plants in the world, based on “green” hydrogen generated with renewable energy. The second project, for which Repsol is investing €20 million, involves construction of a pyrolysis plant, which will be able to convert around 10,000 metric tons per year (m.t./yr) of urban waste into fuels.

Showa Denko expands resin production capacities in China

June 15, 2020 — Showa Denko K.K. (SDK; Tokyo; www.sdk.co.jp) expanded production lines to produce vinyl ester (VE) resin and synthetic resin emulsion (EM) at its Chinese subsidiary Shanghai Showa Highpolymer Co. (SSHP). The expansion has doubled SSHP’s production capacities for EM and VE.

Air Liquide to build air-separation unit for Posco steelmaking site

June 10, 2020 — Air Liquide Engineering & Construction (Frankfurt, Germany; www.engineering-airliquide.com) has signed a new contract with steel producer Posco (Pohang, South Korea; www.posco.com) to design and build an air-separation unit, which will produce oxygen, nitrogen and argon and have a production capacity of 1,700 m.t./d. The new unit will be installed at Posco’s Pohang site and will replace two existing units.

Arkema invests in U.S. anhydrous hydrogen-fluoride production

June 3, 2020 — As part of a longterm agreement with Nutrien Ltd., Arkema S.A. (Colombes, France; www.arkema.com) will invest \$150 million in a 40,000-m.t./yr production plant for anhydrous hydrogen fluoride (AHF) at Nutrien’s site in Aurora, N.C., scheduled to start up in the first half of 2022. The AHF, which will be supplied to Arkema’s Calvert City, Ky. site, will be produced using a naturally occurring element from Nutrien’s phosphate-manufacturing process, replacing the conventional source of mined fluorspar.

HollyFrontier to convert Cheyenne Refinery for renewable diesel production

June 2, 2020 — HollyFrontier Corp. (Dallas, Tex.; www.hollyfrontier.com) plans to repurpose its petroleum refinery in Cheyenne, Wyo. for renewable diesel production. With expected investment around \$125 million, HollyFrontier

intends to cease petroleum-refining activities at the site and produce approximately 90 million gal/yr of renewable diesel at the Cheyenne site. HollyFrontier expects the project will be completed in the first quarter of 2022.

PKN Orlen to establish hydrogen-production hub in Poland

June 2, 2020 — PKN Orlen (Plock, Poland; www.orken.pl) is set to build a hydrogen-production hub in Włocławek, Poland by the end of 2021, ultimately producing up to 600 kg/h of purified hydrogen. The project provides for the construction of a plant for the production of fuel-cell-grade hydrogen, as well as logistics infrastructure and hydrogen refueling stations.

BP licenses PTA technology to Weilian Chemical

May 29, 2020 — BP plc (London, U.K.; www.bp.com) will license its technology for the production of purified terephthalic acid (PTA) to China’s Dongying Weilian Chemical Co., which intends to build a 2.5-million m.t./yr PTA production unit in Shandong province, China. First production is anticipated by the second quarter of 2022.

Dow to scale up polyol production from recycled mattress materials

May 28, 2020 — Dow Polyurethanes, a business division of Dow, Inc. (Midland, Mich.; www.dow.com), plans to install an industrial-scale production facility at Orion Chemicals Orgaform in Semoy, France, which will process discarded mattress foam into polyols through chemical recycling. The installation of the plant is expected to take place during the second half of 2020, with the first batch of polyols expected to be delivered in the first half of 2021.

Clariant to increase mild surfactants capacity in Europe and the U.S.

Clariant (Muttens, Switzerland; www.clariant.com) is expanding production capacity for mild surfactants based on isethionates derivatives. The investment at facilities in Mount Holly, N.C. and Tarragona, Spain will bring additional capacity on stream during the first quarter of 2021.

Mergers & Acquisitions

Dow and Shell team up to develop electric-cracking technology

June 16, 2020 — Shell Chemicals (London, U.K.; www.shell.com/chemicals) and Dow announced a joint-development agreement to accelerate technology to electrify ethylene steam crackers. Using renewable electricity to heat steam-cracker furnaces could become one of the routes to decarbonize the chemical process industries.



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New silica JV to focus on fuel-efficient tires

June 15, 2020 — Tosoh Silica Corp., a member of the Tosoh Group (Tokyo, Japan; www.tosoh.com), recently established a joint venture (JV) with Namhae Chemical Corp. (Yeosu, South Korea). The JV plans to construct a facility to produce silica for use in fuel-efficient tires.

Ascend acquires manufacturing assets in China

June 11, 2020 — Ascend Performance Materials, LLC (Houston; www.ascendmaterials.com) will purchase NCM (Changshu) Co. and Tehe Engineering Plastic (Suzhou), both located at the Changshu Yushan High-tech Industrial Park in eastern China. Ascend plans to expand compounding assets at the site, along with establishing a research and development center that will focus on several application areas, including electronics, 3D printing and films.

Indorama acquires PET-recycling facility in Brazil

June 9, 2020 — Indorama Ventures Ltd. (IVL; Bangkok, Thailand; www.indoramaventures.com) has acquired a 100% equity stake in AG Resinas Ltda., which operates a polyethylene terephthalate (PET) recycling facility in Juiz de Fora, Brazil with a processing capacity of approximately 9,000 m.t./yr.

AGC acquires former AstraZeneca plant in Colorado

June 2, 2020 — AGC Inc. (Tokyo, Japan; www.agc.com) purchased a biopharmaceutical manufacturing facility in Boulder, Colo. The facility, formerly owned by AstraZeneca plc (Cambridge, U.K.; www.astrazeneca.com), includes two 20,000-L bioreactors, and has space for up to four more 20,000-L bioreactors. AGC will prepare for the plant to resume full-scale operations by April 2021.

Arkema completes sale of Functionalized Polyolefins unit

June 2, 2020 — Arkema finalized the €335-million sale of its Functional Polyolefins business to SK Global Chemical Co. (Seoul, South Korea; www.skglobalchemical.com). With sales of around €250 million, the Functional Polyolefins business comprises ethylene copolymers and terpolymers.

Altivia acquires KMCO chemical ethoxylation assets

June 1, 2020 — Altivia Oxide Chemicals, LLC, an affiliate of Altivia Petrochemicals (Houston; www.altivia.com), has acquired KMCO, LLC (Crosby, Tex.; www.kmcolc.com) and its associated chemical-ethoxylation manufacturing assets in Crosby, Tex. The facilities include 31 reaction and distillation trains with capacity for ethylene and propylene

oxide reactions, as well as a broad range of organic reactions to produce surfactants, lubricant additives, fuel additives and a variety of ethoxylation- and propoxylation-based intermediates. Altivia will invest \$25 million to upgrade the facilities, and plans to start up two new oxide reactors by the end of 2020. ■

Mary Page Bailey

Advances in Filtration

Presented here are a few recent developments in filtration, including new cartridge design, automated self-cleaning systems and more

Used for everything from purifying a liquid product, or recovering a solid product from a gas or liquid solvent, to environmental applications such as air-pollution control and wastewater treatment, filtration is arguably one of the most widely used unit operations in the chemical process industries (CPI). As a result, no single filtration technology dominates the CPI. Instead, a wide variety of application-specific methods are constantly being developed and improved upon to handle a smaller class of filtration issues. Recent developments are presented here.

General trends

"Filtration and separation have many drivers," says Chris Wallace, vice president of Technology, Filtration Technology Corp. (FTC; Houston; www.ftc-houston.com) "and at FTC we offer solutions across a broad range of industries and applications. The drive to develop new applications, such as carbon capture, reuse or sequestration, is definitely a hot topic. Also, we recognize increased demand for the products our customers in certain industries manufacture," says Wallace.

"Just consider the impact COVID-19 has had on products related to PPE [personal protective equipment] and the chemical sanitizer supply chain, or on the reduction of demand for other products like fuels. Many facilities have redirected their processes to support this new demand, which impacts their filtration and separation challenges. Based on what we know today, I see the demand for products supporting PPE and sanitization chemicals continuing over the long term, with the reduction in demand for fuel being only a short-term trend.

FTC



FIGURE 1. Invicta is said to offer up to 275% more surface area over cylindrical filters

Of course, environmental legislation is a significant driver for all filtration and separation technologies. It has historically been a driver and will continue to be over the long term," says Wallace.

"Even in tumultuous times, the one thing that remains the same with all our customers is a steady focus on process reliability and improved process efficiencies," says Wallace. "As a result, the trend is for more reliable filtration performance, higher flow capacity, lower clean pressure-drop, longer online filter-life, smaller footprint, lower energy demand, minimal operator exposure to hazardous fluids, and the reduction of waste," he says.

Improved cartridge design

When it comes to filtering liquids, cartridge technology has been a traditional way to remove solids from liquid products, such as fuels and water. "Developments in polymer and fiber technology, non-woven media technology and membrane technology, as well as advancements in filter-testing equipment capabilities have really raised the bar

on what can be done," says FTC's Wallace. "These advancements in filtration media technology and cartridge technology, combined with our ability to analyze particle properties, capture mechanisms, loading and efficiencies on small- and full-scale test stands in our R&D center, have allowed us to redefine expectations upwards. This applies to new requirements driven by our customers' ever-changing needs, as well as to legacy applications," says Wallace.

"For example," Wallace continues, "we see a lot of chemical treatments and additives added to fluid processes. These often-undisclosed additives can impact filtration performance or even cause degradation of a filter or filter media. Additionally, we see demand for fluid processes at higher temperatures, which results in complex chemical and thermal compatibility challenges. Our arsenal of filter media and element construction materials combined with our testing capabilities allows us to offer filter cartridge solutions with proper chemical and thermal compatibility to withstand



FIGURE 2. Automated, self-cleaning candle filters can now be used for filtering molten sulfur, for example

more challenging environments, especially over the extended service life our customers demand," he says.

"We spent many years in our R&D [research and development] center developing what we call Invicta technology," Wallace continues. "After listening to our customers and understanding their challenges and goals, we worked to develop a cartridge technology that solved as many of their issues as possible," he says.

"Before Invicta, the industry had been stuck on cylindrical cartridges, since they were first developed," Wallace explains. "Even our previous patents and technology developments had been focused on cylindrical cartridges. With customer requirements in mind, we focused on the fundamental principles of filtration and disregarded all thoughts of industry norms, of what was expected. The result was a groundbreaking, patent-pending cartridge technology that broke with normal industry expectations and was inclusive of many filtration markets and applications," boasts Wallace.

Invicta (Figure 1) offers a wide

range of chemical and thermal compatibility, maximum effective surface area in the smallest footprint, reduced media face velocity to increase solids loading, and longest online life without sacrificing the reliable effluent quality, continues Wallace. "To top it off, lower pressure drop reduced energy costs, and Invicta's unique coreless design lowered the disposal footprint for our customers, with minimal components and greater packing density in shipping and disposal containers," he says.

"Because of its innovative design qualities, Invicta offers up to 275% more surface area over cylindrical filters," says Wallace. "Although Invicta technology is just hitting the one-year mark in the market, it is already revolutionizing the industry. Our customers are calling it the 'magic filter.'"

Automated self-cleaning

"The trend in liquid filtration is getting away from manually cleaned filters," says José Sentmanat, owner of Liquid Filtration Specialist, LLC (Conroe, Tex.; www.filterconsultant.com). "The old technology of manually cleaned filters, like the horizontal-plate filters, is losing popularity," he says. "First of all, there are very few manufacturers that offer that type of filtration equipment, and the ones that still do are probably wondering where their future business will be," explains Sentmanat. "Yes, there have been self-cleaning filters for a few years now, but the new technology is self-cleaning candle filters. The candle filters offer either a wet cake discharge by backwashing the filter cake off the candle elements or a dry cake discharge by simply blowing back the dried filter cake off the candle elements," he says.

One company offering such technology is Sulphurnet (Culemborg, the Netherlands; www.sulphurnet.com). "In the last few years, we have seen a trend in the filtration market where users

Outotec



FIGURE 3. Outotec's Larox PF-DS double-side pressure filter handles challenging materials with difficult filtration or high cake-washing needs

are changing from big, manually cleaned filters to smaller units and fully automated self-cleaning systems," says Sulphurnet director Jan Hermans. "The result of this is more control of the process, less maintenance, more personal security and more space available on the plant. Besides this, we see a development of stainless-steel materials for fine (low-micron particle size) filtration that which can be cleaned and re-used," he says.

Hermans points to a recent example: "Classically, liquid-sulfur-purification plants are equipped with horizontal pressure-leaf filters, which have to be opened and manually cleaned at the end of a filtration cycle. This work is labor intensive and is a safety risk due to the high temperature of the product. Recently, Sulphurnet has installed the first self-cleaning candle filter [Figure 2] for the filtration of liquid sulfur. This filter can discharge its filter cake in a fully automated way without completely opening the filter system. Since the installation, we have been monitoring the performance of the liquid sulfur filter and it currently shows that this filtration technology will be a very good replacement for the existing technology."

Automated self-cleaning filter systems are also becoming important for other types of filters besides candles. "We see a trend towards

sustainability, increased purity, less waste with lower energy consumption and reduced emissions," says Oskar Sieking, business manager Filtration at Outotec (Espoo, Finland; www.outotec.com). "These drivers push the industry towards fully automated filtration solutions," he says.

"Besides these drivers in existing processes, we see a wide range of developments in renewable processes utilizing raw material of natural origin rather than today's oil-based chemistry," continues Sieking. "These new processes have their specific processing and filtration challenges to the required filtration steps. One of the developments addressing all these drivers is our PF-DS," he points out.

"With the new PF-DS [Figure 3], we can handle fully automatic applications like pigments, with very fine particles and thin cakes," explains Sieking. "From the material-selection point of view, we are now able to offer full FDA [U.S. Food and Drug Administration] compliance for food-grade products like starch."

The PF-DS is a tower press filter where the plate pack is composed of polypropylene membrane filter plates stacked on top of each other. The cake forms between the closed filter plates on the top and bottom side of the filtration chamber — hence the term double-side filter.

The PF-DS combines two proven technologies into one unit. The mechanical operation and frame are shared with the Outotec Larox PF pressure filter while the unique filtration process is powered by the double-side plate pack from Outotec Larox DS filter (earlier known as Hoesch DS).

Key features and benefits of this technology include: excellent handling of difficult and slow-filtering materials; guaranteed cake discharge, even with challenging material; multiple cake-washing options; options for efficient and automatic in-situ cleaning in place (CIP); the ability to handle corrosive process conditions; and more.

Sieking also adds: "At our Dewatering Technology Center, we work

on optimization of filtration and process parameters for new applications like the bio-based materials. On the filter cloth side, we cooperated closely to develop filter cloth qualities for a better and sharper screening of fine particles."

Corrosion resistance

"Over the last few years, customers have been more and more asking for filtration technologies and processes that reduce operating costs and avoid production downtime," says François Fevrier, Chemicals Business Development Director at Andritz Separation (Graz, Austria; www.andritz.com). "The latter has been one of our many focus areas, specifically the development of a corrosion-resistant filtration technology."

To meet these challenges, Andritz recently introduced its CORES vacuum-drum filter (Figure 4). "The structural design of this new filter is, dependent on size, made out of steel or completely out of glass reinforced plastic (GRP)," explains Fevrier. "In addition, all parts in contact with the product are covered with a layer made of corrosion-resistant, non-reinforced plastic, which is commonly used in such industries like polypropylene (PP) or polyvinylchloride (PVC) manufacturing. Furthermore, some internal wetted parts can be completely designed out of resistant plastic and will be welded together with external surfaces made out of plastic to

Andritz



FIGURE 4. Andritz's patented sandwich design of the CORES technology provides a permanently chemically resistant surface and can be made with different materials to ensure resistance to chemicals



FIGURE 5. MYTEX Blocks incorporate customizable, textile-based, flexible and back-washable flat sheets that are formed into self-supporting, stackable blocks

have a closed surface for these corrosive applications. No single screw will remain in the wetted process area; therefore a maximum on corrosion resistance in highly corrosive media is given," Fevrier says.

Water and wastewater treatment

"In the field of water filtration, the industry is driven by more and more huge projects in Asia for both water and wastewater treatment," says Carsten Bachert, CEO at WTA Technologies GmbH (Gotha, Germany; www.wta-tec.com). "As one outcome, the price for water production dropped to \$0.40/m³ of desalinated water. One effect of reaching such price level is the eroding margin for contractors and suppliers. Consequently, the prices for filters went down over the last two years," he says.

"To catch up with this trend, WTA Technologies decided to invest in a fully automatic production line for submerged membrane modules," says Bachert. "This line was commissioned recently and ensures outstanding quality at low production costs. But the real challenge is not to standardize productions for huge quantities, it is more to use such a tool and still offer a customizable product for a price of a standardized one," he says.

"It is not a new application, but for the first time, we are able to retrofit submerged filtration plants with our membrane blocks," says Bachert. "Usually, the genuine supplier gets an order automatically from his client for changing the membranes," explains Bachert. "As these submerged membrane module markets do not know anything about 'me-too' products, the spare business is secured just by being selected as supplier during the construction phase."

What WTA Technologies does differently is to manufacture membrane blocks that fit into the frame of the genuine supplier. "Just by changing the membrane blocks and adopting the permeate connection, the membrane module can be retrofitted with latest state-of-the-art filtration technology," says Bachert. "As the membrane block can be operated by gravity

or by use of a permeate pump, with or without back-wash the process control and process philosophy is not touched," he says.

The company's latest product is MYTEX Blocks (Figure 5), a customizable, textile-based, flexible and back-washable flat sheet. These self-supporting, stackable blocks allow the highest packing density. They consist of 2-mm membrane sheet with an 8-mm channel between the sheets; no extra frame is needed to support the membrane blocks for up to six blocks stacked on each other. A membrane-block intensity of 174 m²/m³ is said to be one of the highest available for plate/sheet configurations. The blocks are easy to service, because they open from all sides, and are easy to handle without special tools, cranes and so on. Despite the high packing density, the blocks have a low propensity for clogging due to the wide (8-mm) channels between the sheets.

The MYTEX submerged membranes have been used in a number of applications. Some examples include: integrated for use as a membrane bioreactor; sequential use as a polishing step in tertiary treatment; sequential use as sludge thickener in aerobic digestion; and for direct filtration of medium- to high-solids water and wastewater.

Gerald Ondrey

Focus on Temperature

The world's first temperature transmitter with Bluetooth

Last November, this company launched its iTEMP TMT71 and TMT72 single-channel transmitters (photo) with user-friendly operation concept and wireless communication via Bluetooth in conjunction with highly accurate and reliable measurements. The technology is said to offer significant improvements in process efficiency, plant availability and reduced costs. The transmitters are available with an integrated Bluetooth interface that



enables users to wirelessly display measured values and perform configuration tasks. The device is easy and fast to operate using the company's SmartBlue application (app). The device can be configured without the need to previously install device drivers, since they are already stored in the transmitter's electronics. The configurable transmitters are compatible with signals from resistance thermometer devices (RTD), thermocouples, resistance (Ω) and voltage transmitters (mV), and provide an output via the 4–20-mA signal or the HART 7 communication (TMT72). — *Endress + Hauser, Greenwood, Ind.*
www.us.endress.com

Shakers for continuous operation and temp. control

The new Varioshake product line (photo) comprises ten shakers in three sizes with five different shaking motions, as well as three shaking incubators in three sizes with a circular motion. The shakers are suitable for many laboratory applications, such as



for mixing liquids or powders, prevent sedimentation or for oxygen enrichment and sample preparation. The

electronics system controls a soft start. With a space saving of up to 35% compared to the previous model, Varioshake shakers are adapted to the limited space available in laboratories. The shakers are available in versions with a load-bearing capacity from 8 to 30 kg and work surfaces up to (676×540) mm². Depending on the model, the devices are equipped with user-friendly analog or digital control. — *Lauda Dr. R. Wobser GmbH & Co. KG, Lauda-Königshofen, Germany*
www.lauda.de

Temperature-monitoring relays with more functions

This company has transformed the temperature-monitoring relays from its Sirius portfolio. The new Series 3RS2 devices (photo) are available in analog and digital versions. They use sensors to measure the temperature in industrial control cabinets, of engine, bearing and transmission oils, or cooling liquids, preventing plant malfunctions or damage that can result when

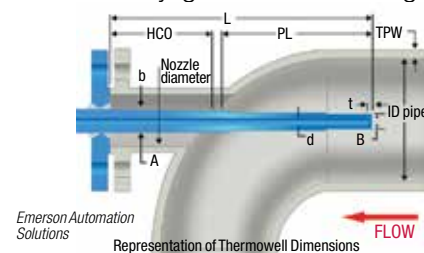
exceeding or dropping below certain limit values. These relays can also monitor heating, air-conditioning, and ventilation systems (HVAC), solar collectors, heat pumps and hot-water supply systems. The devices in the new Sirius 3RS2 series are approved for safety applications up to SIL 1 / PL c, for use in industrial furnaces, as well as for monitoring burners and ATEX applications. Compared to predecessor models, they feature expanded functionalities, a narrower design and easier operability. — *Siemens Smart Infrastructure, Zug, Switzerland*
www.siemens.com



Reduce thermowell-design time to 15 min with this tool

The new Rosemount Thermowell Design Accelerator eliminates the largest "pain point" of temperature process design — manual ther-

mowell iterations — significantly increasing operational efficiencies and cost savings. The free, online thermowell-design tool is easy to use and intuitively guides users through



complex projects, saving hours of wasted labor and resources. Users will be able to automatically iterate up to 1,000 thermowell tags with a single click — all optimized for their process conditions. On average, engineers can spend 50 h completing thermowell calculations for a single project. Nearly 20 variables related to process conditions and thermowell dimensions are used to find a safe and efficient solution. Temperature points often need to be recalculated three to four times using traditional trial-and-error methods before passing global standards for safe operation outlined by The American Society of Mechanical Engineers (ASME). Using the Thermowell Design Accelerator, engineers can reduce design ideation time to just 15 min, says the company. The new tool features a dynamically changing image (photo) that intuitively leads users through thermowell designs. — *Emerson Automation Solutions, Shakopee, Minn.*
www.emerson.com

Dual-channel transmitters with HART compatibility

This company has introduced six new universal temperature transducers. These new additions to the MACX MCR family (photo, p. 17) are loop-powered and have two channels. The new modules include two non-Ex and two Ex I versions in two different mounting formats: head-mount and DIN rail-mount. The temperature transmitters support more than 28 different temperature sensors. The modules will also accept –20 to 100 mV and linear



Phoenix
Contact USA

resistance ranges from 10 to 2,000 ohms. On the output side is a dedicated 4–20-mA signal with HART communication. At just 12.5 mm wide, the DIN rail-mountable modules save space in the cabinet. The modules are rated up to SIL 2 according to IEC/EN 61508, so they can be easily designed into safety-related industrial automation applications. Approvals include ATEX, CSA, FM, EAC, and UL Class I, Division 2, making them suitable for worldwide use. — *Phoenix Contact USA, Middletown, Pa.*
www.phoenixcontact.com

Continuously monitor industrial equipment with this device

By providing continuous, remote thermal monitoring of electrical panels and other components, the K6PM Thermal Condition Monitoring Device (photo) lowers the time and cost required for critical equipment inspections and minimizes the risk of unplanned shutdowns. Device failures have various causes, most of which lead to overheating and subsequent insulator breakdown. Using the K6PM, users can know that their equipment is being monitored on a continuous basis for any abnormalities resulting from overload, vibration, condensation or other causes. Automated data collection and analysis

Omron Automation



enables even inexperienced personnel to recognize a potential device failure early on and take action to prevent serious problems. — *Omron Automation, Hoffman Estates, Ill.*
www.automation.omron.com

Non-contact, hand-held temperature measurement

The uncooled thermography cameras in the VarioCAM HD series (photo) provide detailed images of heat distributions and measure temperatures with high precision and without contact. Their high resolution and individual radiometric calibration ensure optimal quality of thermographic measurement data. The

hand-held and stationary infrared (IR) cameras are used for research and development in the field of renewable energy or in the production of light constructional components, for example. They are used to detect heat losses or temperature anomalies, thus making an essential contribution to climate protection and production efficiency. There is increased demand for thermographic cameras at the moment for use in fever detection at transport hubs such as airports or railway stations, where IR cameras can be used to efficiently check



Jenoptik

large groups of people with the help of high-resolution non-contact temperature measurement technology. — *Jenoptik AG, Jena, Germany*
www.jenoptik.com

Compact, high-definition thermal science cameras

The A8580 Series of thermal science cameras (photo) is a 1.3 megapixel, entry-level cooled camera designed for a wide range of industrial, and product research-and-development (R&D) applications. This camera records blur-free images of high-speed targets, offers a wide range of precision, manual and motorized lenses, and integrates seamlessly with the new FLIR Research Studio thermal analysis software. The A8580 Series includes four midwave-IR models, as well as a longwave model that provides better uniformity and stability through cooldowns than other, similar cameras. This new camera also offers wide temperature-calibration ranges, reducing the need for repeated testing to fully measure a high dynamic scene and fast integration times. All five models produce sharp, 1,280 × 1,024 thermal pixel imagery for a 30% improvement over previous models. — *FLIR Systems, Inc., Arlington, Va.*
www.flir.com



FLIR Systems

Bimetal thermometers qualified in accordance with ASME & EN

Introduced at the end of 2018, the model TG53 bimetallic thermometer (photo) conforms to the ASME B40.200 standard and is manufactured for the inch unit of measure. The model TG54 has been qualified in accordance with the EN 13190 standard. The thermometers are available in a wide selection of nominal sizes and scale ranges (between –70 and 600°C (–94 and 1,100°F). The instruments have a high overtemperature resistance and are certified for low ambient temperatures (down to –50°C. With ATEX approval, IP65 ingress protection (optional up to IP68) and, in the version with liquid damping, they are also suitable for harsh operating conditions.



WIKA Alexander
Wiegand

— *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.com

New multifunctional temperature calibrator

The MC6-T (photo) is a multifunctional temperature calibrator and communication device that can provide accurate reference measurements and simulations for temperature, pressure and electrical signals, such as resistance, current, voltage, pulses and frequency, together with HART, Profibus PA and Foundation Fieldbus communications. According to the manufacturer, the MC6-T can replace many individual devices, such as a temperature block, temperature calibrator, pressure calibrator, field communicator or datalogger. The device also offers the capability to calibrate short and flanged sanitary sensors, which is typically not possible with traditional temperature dry-blocks. The MC6-T is available in two different models: MC6-T150 for low-temperature applications and the MC6-T660 for higher-temperature calibrations. — *Beamex, Inc., Marietta, Ga.*
www.beamex.com/us



Beamex

— *Beamex, Inc., Marietta, Ga.*
www.beamex.com/us

Gerald Ondrey



Leybold



Veolia Water Technologies



Endress + Hauser



Pfeiffer Vacuum

Digitalization adds value to compressor and blower units

AERprogress is a suite of customized digital services for compressors and blowers from this company's Delta series. With AERprogress, the extensive recording and evaluation of energy-related process data enables efficient control of the assemblies in combination, which can considerably reduce energy costs, says the company. Furthermore, operators can benefit from greater process safety, transparency and reliability, since this information can be used to implement data-supported service and maintenance concepts. — *Aerzener Maschinenfabrik GmbH, Aerzen, Germany*
www.aerzen.com

Two new sizes of turbomolecular pump introduced

This company has expanded its Turbovac i/iX series of turbomolecular pumps with the addition of two new sizes — the 850 i/iX (photo) and 950 i/iX. The two new pumps are characterized by extended operation, longer system life and lower operating costs, according to the manufacturer. They are designed for a wide range of applications, including R&D and analytical processes, as well as industrial processes that require a clean and stable high- and ultrahigh vacuum, such as in coating, heat treatment, thin-film research and helium recovery. The new models in the Turbovac i/iX family provide improved vacuum performance, offering higher pumping speeds and compression values. — *Leybold, a part of Atlas Copco's Vacuum Technique, Cologne, Germany*
www.leybold.com

A skid-mounted RO system for high-purity water production

Through its business unit Solys, this company launched the Sirion Pro range, a simplified version of the Sirion RO (reverse osmosis) range (photo). A compact, plug-and-play system that integrates Aquavista digital services, Sirion Pro offers more basic features — a choice of four different options — at a lower cost. Both Sirion Advanced and Sirion Pro are capable of removing up to 98% of dissolved inorgan-

ics and over 99% of large dissolved organics, colloids and particles, says the manufacturer. Applicable to most industrial sectors and reuse projects, the product range includes 11 models covering permeate flowrates from 100 to 5,000 L/h. — *Veolia Water Technologies, Saint-Maurice, France*
www.veoliawatertechnologies.com

This turbidity sensor withstands aggressive media

The new Turbimax CUS50D sensor (photo) is an absorption sensor for turbidity and suspended-solids measurement in unfavorable environments. Its robust design is made to withstand aggressive media and is suitable for applications in industrial wastewater treatment or chemical processes. Turbimax CUS50D measures turbidity and suspended solids (attenuation of light in accordance with ISO 7027) reliably and accurately — even in very dark liquids and sludges. The special Teflon-derivative sensor-measurement surface minimizes the risk of dirt accumulating, thus guaranteeing a stable and consistent measurement. Surface contamination is removed by the sensor's air-cleaning system — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

Leak detector for easy and accurate "sniffing" operations

This company has launched the ASM 306 S (photo), which addresses any industrial leak-detection "sniffing" applications, especially in refrigeration and air-conditioning processes. This new leak detector is highly sensitive (10^{-7} mbar L/s), precise and accurate. Leakage control using sniffing measurements before the final refrigerant gas charge is one of the last steps of the production process. This requires the highest testing reliability to increase productivity and quality levels. The ASM 306 S helps to meet those challenges. The product combines the advantages of a proven technology regarding sensitivity, accuracy and repeatability. The ASM 306 S has been designed to offer fast and repeatable measurements, whether He or H₂ is used as the tracer gas. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.com

Access and control flowmeters from a smartphone

Edge Flow Electronics (photo) interface with positive-displacement or turbine flowmeters to provide better access, understanding and control of processes — in some cases, from a smartphone. When installed on a flowmeter, Edge devices can force the sensor to output a frequency or analog signal output for greater flexibility when interfacing with readout equipment or control rooms. Modbus output also adds system compatibility for more advanced operations. A Bluetooth mobile application supports innovative signal processing, allowing users to monitor and program flowmeters from a smartphone. Mobile and PC-based applications streamline installation, configuration and troubleshooting. With basic scaling and advanced functions, the user-friendly application allows for remote correction of non-linear flowmeters to maintain a linear analog output. — *AW-Lake Co., Oak Creek, Wis.*

www.aw-lake.com

Low-maintenance, heavy-duty flexible conveyors

The new Flexifeeder line of flexible screw conveyors (photo) offers expanded capability with less frequent maintenance. Each Flexifeeder is matched to the individual user requirement, using both this company's extensive installation database and complementary laboratory testing. The use of controlled vibration at the inlet hopper eliminates material packing and tunneling, and encourages more balanced loading of the conveying screw. This, along with a simple and robust drive system, results in a more uniform repeatable conveying rate and dramatically reduced maintenance. Flexifeeders are available in capacities up to 1,500 ft³/h and single-unit conveying lengths of 50 ft. — *Vibra Screw, Totowa, N.J.*

www.vibrascrew.com

Multipurpose furnaces streamline loading and unloading

New GS2026 bench-mounted box furnaces (photo) include a spring-assist vertical-lift door that allows for effortless loading and unloading even

at high temperatures. The furnaces are controlled by an industrial control system that includes a Eurotherm temperature control, overtemperature protection and a recirculation fan for uniformity. The heating elements are located on both sides and at the top and bottom, which enables equal heat distribution from all sides. This element distribution can achieve a uniformity gradient of $\pm 10^{\circ}\text{F}$. Standard units include a sheathed thermocouple, a slot in the door for access into the furnace, a powder-coated machined case, ceramic hearth plate with standoffs, a door limit switch that turns the power to the elements off if the door is opened, an on/off toggle switch with control fusing and a power plug. An optional angle iron stand and vent kit are also available. The GS2026 has an operating voltage of 208, 220 or 240 V single-phase, 60 or 50 Hz. — *L&L Special Furnace Co., Aston, Pa.*

www.llfurnace.com

Continuous processors quickly mix fast-reacting materials

This company's Continuous Processors (photo) feature a proprietary design that ensures the fast-reacting materials used to process rigid polymeric foams are mixed, gelled and reacted entirely within the sealed reactor barrel before they begin to cure. Allowing foam formation and curing to occur entirely downstream, the Continuous Processors eliminate the risk of premature curing inside the barrel, along with its requisite, labor-intensive cleaning and safety concerns. Developed for producing foams, such as polyurethane, polystyrene, polyethylene and other materials that cure instantaneously, the Continuous Processors strategically introduce isocyanates, blowing agents and other reactants at key points in the process to efficiently produce a uniform, homogeneous dispersion of materials within a tight residence time. Targeted specifications for strength, cell morphology, thermal conductivity and other properties are consistently achieved. — *Readco Kurimoto, LLC, York, Pa.*

www.readco.com

Mary Page Bailey and Gerald Ondrey

AW-Lake



Vibra Screw



L&L Special Furnace



Readco Kurimoto

Cyclone Separators

Department Editor: Scott Jenkins

Removing solids from a stream of air or other gases is an important operation across virtually all sectors of the chemical process industries (CPI). In many cases, gas-solid separation is motivated by the need to reduce environmental impact and health hazards, as in removing particulate matter from exhaust gas. In solids-processing operations, such as milling, grinding, packaging and others, it is often necessary to remove dust from air to recover product or protect equipment. This one-page reference focuses on one type of gas-solid separator: the cyclone.

Operating principles

A cyclone works on the principle of inertial separation. A stream of dust-laden air or gas is introduced tangentially to the top of a vertically oriented, cylindrical collection chamber with a conical, tapered end at the bottom. The manner by which the gas enters the chamber creates a helical airflow pattern, where the gas rotates down the chamber toward the tapered bottom (Figure 1). The swirling motion of the gas has two components — a downward-directed spiral movement for the outer stream, and a rotating, upward-moving inner stream.

Due to their greater mass, solid particles contained in the gas stream are pushed outward due to the centrifugal force that results from the rotating airflow. Since they have too much inertia to follow the path of the gas stream, particles are pushed against the interior wall of the cyclone cylinder and fall downward toward a collection device fitted at the bottom of the cyclone. The solid particles often exit the bottom through a spring-loaded flap valve or a rotary valve. Meanwhile, the solids-free gas rotates upward toward the gas outlet at the top of the chamber.

In addition to air-pollution control and dust-control applications, cyclones also serve other purposes in CPI applications. These include the recovery and recycling of catalysts in petroleum refineries, the recovery of freeze-dried coffee in food pro-

cessing plants, and for capturing sawdust in a lumber mill, among others.

Advantages and limitations

Among the reasons that the use of cyclones is so widespread are that they have no moving parts, can withstand high-temperature gases and harsh operating conditions, and are relatively inexpensive in terms of capital costs. Because of this, in air-pollution-control applications, cyclones are often used as a pre-treatment step that is followed by an electrostatic precipitator or a filter. The limitations of a cyclone can include low collection efficiencies for small particles, and relatively high operating costs due to the power required to overcome a large pressure drop. Cyclones are commonly used to separate particles greater than 5 μm in size.

Standard dimensions

Standard configurations of industrial cyclones for particulate collection and removal are available as a result of empirical measurements compiled over time. All dimensions are related to the body diameter of the cyclone so that the results can be applied generally. For example, classic research suggests that the height of the inlet for a conventional cyclone is half of the body diameter and the length of the chamber is twice the diameter. Further, the length of the cone is twice the diameter and the dust outlet is one quarter of the diameter. Other important dimensions include the cleaned-gas outlet ($0.5 \times \text{dia.}$) and the width of the dirty-gas inlet ($0.25 \times \text{dia.}$).

Separation efficiency varies greatly depending on the particle-size distribution of the solids contained in the gas, and the cyclone geometry. Cyclones are often grouped into three categories: high-efficiency, conventional and high throughput. Standardized dimensions have been developed for each category. In general,

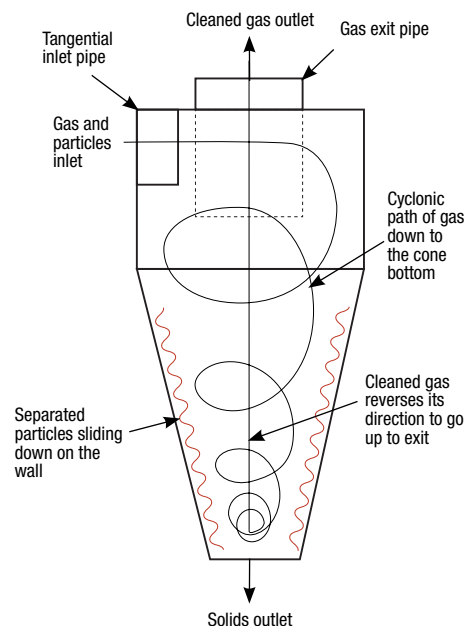


FIGURE 1. Cyclones have no moving parts, so the capital costs and maintenance costs are relatively low compared to other gas-solid separation approaches

operating costs increase with efficiency (higher efficiency requires higher inflow pressure). A small-diameter cyclone generates greater centrifugal force than a larger-diameter device.

Design considerations

Properly designed cyclones can remove nearly every particle in the 20- to 30- μm range. Typical cyclone separators have efficiencies of 70–90%. Gas inlet velocities should be in the range of 100 to 150 ft/s, but may be limited by re-entrainment of dust particles or by unacceptable pressure drop. At the tapered end of the chamber, where the gases reverse their direction of travel, higher gas velocities are experienced, and this can re-entrain finer dust particles (reducing separation efficiency). To avoid this, cyclone design and operation should seek to prevent solids from accumulating in the cone region. ■

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Isopropyl Alcohol Production from Acetone

By Intratec Solutions

Isopropyl alcohol (also known as isopropanol or 2-propanol) is a colorless and flammable liquid with a strong odor. Isopropyl alcohol was among the first petrochemical products to be industrially manufactured — it has been produced since 1920.

The main applications of isopropyl alcohol are as a chemical intermediate, and as a solvent in the manufacturing of cements, primers, paints, varnishes, skin cleaners, perfumes, lotions, shampoos and deodorants. It is also used as a disinfectant and antiseptic.

The process

The present analysis discusses an industrial hydrogenation process for isopropanol production. The process comprises two main sections: (1) reaction; and (2) purification.

Reaction. Hydrogen gas is compressed and fed, along with liquid acetone, to the upper part of a circulation reactor. The circulating mixture passes through a gas-liquid separation vessel. Part of the liquid is cooled — removing the heat generated by the exothermic reaction — and recycled to the reactor. The remainder is cooled and routed to a second reactor, followed by a second vapor-liquid separation stage. The liquid portion obtained after the second vapor-liquid separation is sent to the purification stage. The vapor portion is mixed with the vapors from the first gas-liquid separation and also sent to the purification stage.

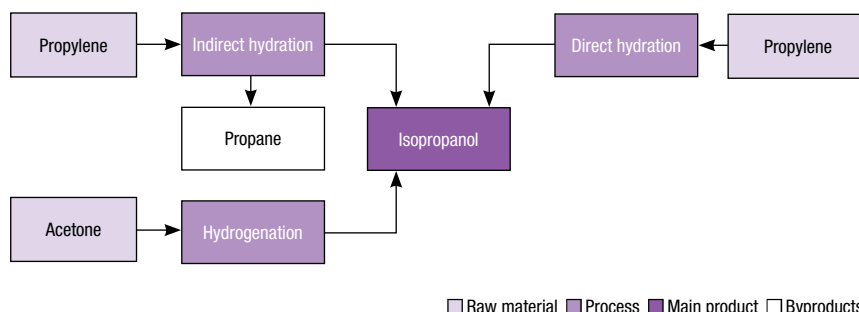


FIGURE 2. Isopropanol production pathways can begin from both propylene and acetone

Purification. In the purification step, the vapors from the reaction are fed to a condenser, where isopropanol and unreacted acetone are recovered. Most of the uncondensed vapor is recycled to the hydrogen compressors. The remaining part of the hydrogen-rich gaseous stream, as well as the condensate from the condenser and the liquid product from the reaction are fed to a deaeration tank to remove any gases dissolved in the crude liquid product. The crude product is then dehydrated with molecular sieves, and is finally fed into a purification column, from which purified Isopropanol product is withdrawn as a side stream. Low-boiling components are separated as the column's overheads product, while high-boiling impurities are obtained as the bottoms product.

on the other hand, is transformed into isopropanol via a hydrogenation process. Figure 2 presents three different pathways for the production of isopropanol.

Economic performance

The total operating cost (including raw materials, utilities, fixed costs and depreciation costs) estimated to produce isopropanol was about \$940 per ton of isopropanol in the third quarter of 2016. The analysis was based on a plant constructed in the U.S. with the capacity to produce 60,000 metric tons per year of isopropyl alcohol.

This column is based on "Isopropyl Alcohol Production from Acetone – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/isopropyl-alcohol-production-cost.

Edited by Scott Jenkins

Production pathways

The two main starting materials for isopropanol manufacture are propylene and acetone. Propylene can be reacted with water directly, or indirectly (in the presence of sulfuric acid), to form isopropanol. Acetone,

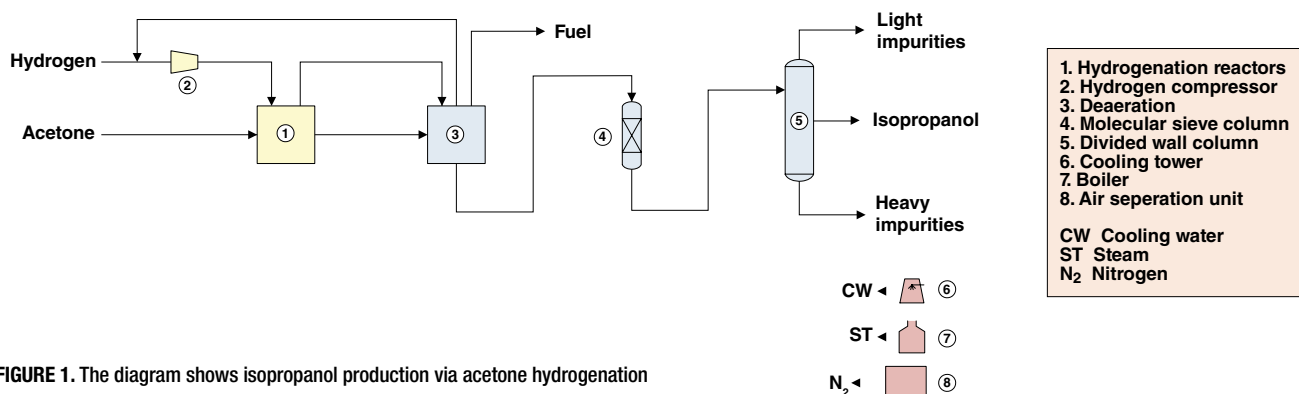


FIGURE 1. The diagram shows isopropanol production via acetone hydrogenation

Controlling Reboilers Heated by Condensing Steam or Vapor

Methods for controlling reboilers in distillation towers are central to good reboiler operation and tower stability. Control valves can be located in the steam-inlet line or in the condensate-outlet line. This article updates guidance for key considerations and practices using both schemes

Henry Z. Kister
Fluor Corp.

IN BRIEF

VARIABLES THAT REGULATE BOILUP
HEAT TRANSFER MECHANISMS
DYNAMIC RESPONSE
CONDENSATE REMOVAL AND REBOILER SEAL LOSS
ENERGY EFFICIENCY AND CAPITAL
FOULING, CORROSION AND THERMAL STRESS
STEAM TRAPS
STARTUP AND LOW-RATE OPERATION ISSUES
FLOW ISSUES WITH THE VAPOR-INLET VALVE
TUBE LEAKS
FLASHING AND HAMMERING
CONDENSATE POTS
STRENGTHS AND WEAKNESSES

A large fraction of distillation tower reboilers, possibly most, are heated by condensing vapor. Typical examples are steam reboilers, refrigeration vapor reboilers, and heat-integrated reboilers that condense overhead vapor from the same or a different tower. For these reboilers, the control valve can be located either in the steam (or vapor) inlet line or in the condensate outlet line.

The two methods are different in principle and operation, have different strengths and weaknesses, and require different measures to achieve trouble-free operation.

The selected method, as well as the features added to overcome its weaknesses, is central for good reboiler operation, performance and tower stability. The literature has some excellent reviews [1, 2] on this subject, but these reviews have last been updated three decades ago. Recent excellent sources [3] have only partially addressed some of the key considerations. This article aims to fill in the gaps, combining the old knowledge with the recent experiences into a detailed updated guide to the key considerations, features and practices that can improve reboiler control and operation.

Variables that regulate boilup

Reboiler control should provide effective response to column disturbances, isolate the column from heating-medium disturbances and adequately dispose of the condensate. The best variable for manipulating column boilup is selected when the column's overall control philosophy is devised [1–4]. In most cases, boilup is regulated either to maintain a constant rate, or to achieve a desired prod-



Photo courtesy: Fluor Corp.

uct purity, normally in the bottom section.

When boilup is kept constant, the reboiler control valve is usually manipulated by a heating-medium flow controller or by a Btu controller. When boilup is regulated to achieve a desired product purity, the reboiler control valve is directly or indirectly manipulated by a tray-temperature controller, or by a product analyzer, or by the tower base level. Indirect manipulation uses a cascade controller that resets the setpoint of the heating-medium flow controller. The flow controller, in turn, regulates the reboiler control valve. Temperature, analyzer or level regulation of column boilup in cascade mode generally gives far smoother and superior response compared to direct manipulation. Nevertheless, direct manipulation is often satisfactory.

Oscillations and sluggishness are far more troublesome and interactive when boilup controls product purity, rather than when boilup is kept constant. This is because the temperature or composition controller feeds back fluctuations in boilup as delayed signals, calling for additional manipulative actions. The feedback interaction is most troublesome when a non-optimal temperature-control tray is used. Procedures for identifying the best temperature-control tray(s) are discussed elsewhere



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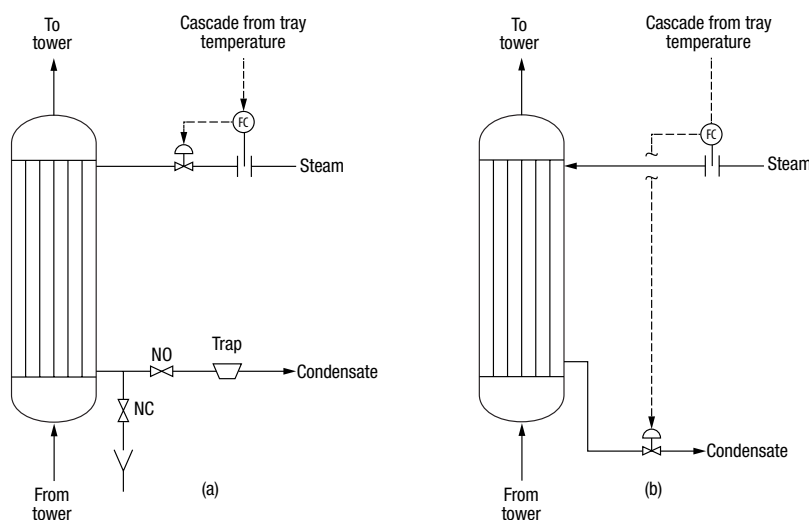


FIGURE 1. There are two basic reboiler-control schemes: a control valve can be positioned in the vapor-inlet line (left) or in the condensate outlet line (right)

[1, 3, 5]. The author experienced a case where this feedback rendered a sluggish boilup control system inoperable during even mild upsets.

The discussion in this article generally applies regardless of the variable that regulates boilup and the directness of control, but the need to avoid oscillating or sluggish boilup manipulation is emphasized when boilup is manipulated to achieve a desired product purity.

Heat transfer mechanisms

Reboiler heat transfer is governed by Equation (1).

$$Q = U A \Delta T \quad (1)$$

Where Q is the heat transfer rate, Btu/h; U is the heat transfer coefficient, Btu/(h ft² °F), A is the reboiler tubes' heat transfer area, ft², and ΔT is the temperature difference between the condensing heating medium and the process.

When the control valve is in the reboiler inlet line (Figure 1a), heat transfer rate is regulated by varying the reboiler condensing pressure and therefore, the reboiler condensing temperature, and in turn, the ΔT . When additional boilup is needed, the valve opens and raises the reboiler pressure, which increases the reboiler ΔT , which in turn increases the boilup rate. The steam trap removes all condensate, so that the reboiler tube

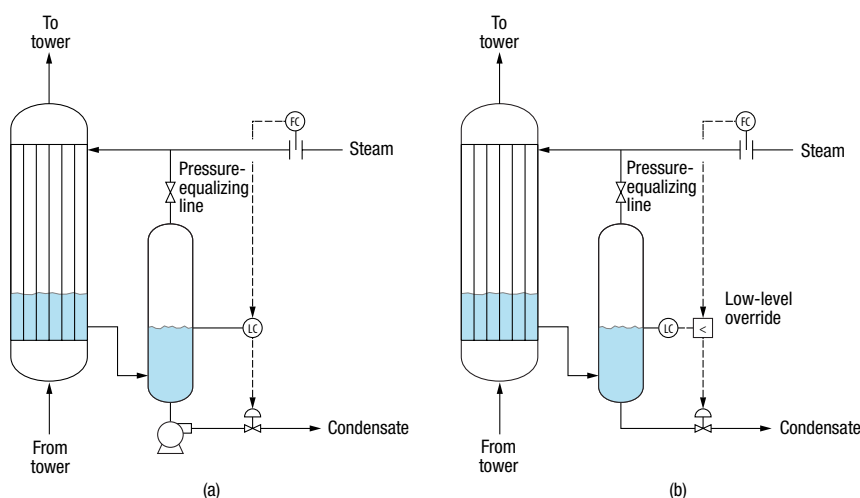


FIGURE 2. These diagrams show the condensate-outlet control scheme with a condensate pot. In 2a, it is achieved via condensate pot level, and in 2b, with condensate-pot level override

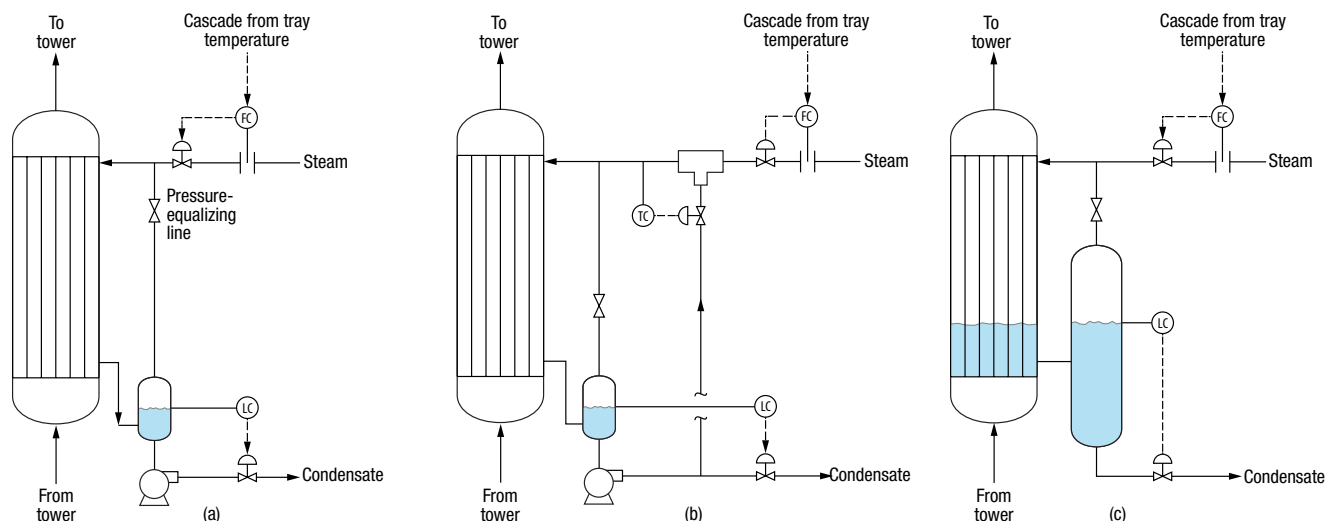


FIGURE 3. The diagrams show a steam-inlet control scheme with condensate pot. In 3a, the scheme includes a pump; in 3b, it has a pump and condensate recycle to desuperheat steam; and in 3c, the level is maintained in the reboiler

area, A , is fully utilized for condensation. In the absence of constraints, there is only minor subcooling, if any, of the condensate.

Instead of controlling flow to the reboiler, some systems control the reboiler pressure. Controlling reboiler pressure is not recommended because the relationship between the pressure and the condensing temperature (and therefore the boilup-pressure relationship) is highly non-linear. Further, the boilup-pressure relationship changes as the reboiler fouls and when the heat-transfer coefficient varies.

When condensate flowrate is manipulated (Figure 1b), the condensate outlet valve maintains a liquid level in the condensing side of the reboiler. The only reboiler tube area available for condensation is that above the liquid level. The tube area submerged under the liquid level performs no condensation, although it subcools the condensate. Vapor condenses at essentially the supply header pressure, keeping the ΔT constant. When additional heat is needed, the control valve opens, lowering the condensate level in the reboiler, which exposes more reboiler tube area for condensation. In turn, this increases the heat transfer rate. Here, A is varied in Equation (1). Due to the submergence of tubes under the liquid level, the condensate comes out subcooled.

Dynamic response

The dynamic response of the vapor-inlet control scheme is far superior to

that of the condensate-outlet scheme. Manipulating the inlet valve changes the reboiler pressure, ΔT and heat transfer rate almost instantaneously. In contrast, the condensate-outlet valve has no direct effect on vapor flow. Condensate flow determines submergence level, and this level changes slowly. Reboiler vapor rate and heat transfer tread on the heels of the level change. Dynamically, this slow response renders manipulation of vapor flow a superior means of control.

The response time of the condensate-outlet control scheme depends on the condensate level in the reboiler. To achieve, say a 10% increase in condensation area, much more liquid needs draining when the level is near the reboiler bottom than when the level is near the top. The response to a condensate flow change therefore accelerates as the condensate level rises. Where the response is overly fast, it may be unstable [2]; and where the response is relatively slow, it may be sluggish. This issue is even more accentuated in horizontal reboilers, where the heat-transfer area change with condensate liquid level is highly non-linear.

With the vapor-inlet valve scheme, the measurement and the valve are both on the same stream, and the valve opening directly and quickly affects the vapor flowrate. In the condensate-outlet scheme, the measurement is on the vapor line, but the valve is on the condensate. Changing the condensate valve opening does not immediately affect the vapor flow.

The relationship between the two is complex and non-linear [3]. In some cases, the condensate level takes longer to rebuild than to drain. This can actually be advantageous when over-reboiling is less troublesome than under-reboiling. Some useful guidelines for tuning the controllers were provided by Smith [3].

One study [6] found that with slow columns, whose time constant is more than four times the reboiler time constant, the dynamics inferiority of the condensate valve scheme becomes less pronounced, and both schemes behave dynamically the same. This coincides with the author's experience (for example, Ref. 7, Case 26.1) of the condensate-outlet valve scheme working well when correctly configured in large trayed towers.

In some thermosiphon reboilers, especially under vacuum, heat-transfer coefficient and therefore, the heat duty, are sensitive to the net liquid driving head [1, 9]. In the condensate-outlet scheme, condensate-side level fluctuations vary the net driving head and can likewise destabilize reboiler operation.

The vapor inlet scheme is more effective than the condensate outlet scheme in terms of filtering out disturbances in the steam supply and preventing them from upsetting the tower [6, 10].

Condensate removal and reboiler seal loss

If the condensate valve cannot drain all the condensate that the reboiler

generates, a maximum vapor flow-rate may be reached with condensate still covering a portion of the tubes. The remedy depends on the cause of the problem. If there is a sufficient pressure difference between the reboiler and the condensate header, it may be sufficient to re-size the valve and the condensate line, or both. If the pressure difference is small, a condensate pot with a pump (Figure 2a) may be needed.

The converse phenomenon can be even more troublesome. When the reboiler cannot condense vapor as fast as the condensate valve removes liquid, the liquid seal in the reboiler may be lost, resulting in vapor passing into the condensate system. Without the seal, vapor tends to channel through the reboiler, causing a dramatic loss of heat transfer, and in the case of steam, also hammering in the condensate system. One seal-loss incident in a reboiler condensing refrigerant vapor, using the control system in Figure 1b, has been described in detail [7, 8]. Many other seal-loss incidents have been experienced by the author and others [11, 12]. Losing the seal is more

likely to occur when the reboiler is fouled or pushed to the limit and the liquid level is low. To regain the seal, the condensate valve needs to be heavily throttled [7, 8, 11].

There are several ways of preventing this seal loss. The scheme in Figure 2a, but without the pump, is one option. Alternatively, the setup in Figure 2b can be used. Here, the flow controller normally regulates the condensate valve, with the level override cutting in whenever the level falls too low. The level override should not be set at a vertical height much greater than the bottom of the reboiler. Otherwise, some of the tubes will always be submerged and the effective reboiler capacity will be reduced. Often, especially in vertical reboilers, the liquid level in the condensing side of the reboiler can be monitored and used for level override control, so the drum can be omitted.

Finally, there are two “poor person’s” solutions. One is to monitor the condensate temperature leaving the reboiler. With the Figure 1b scheme, the condensate is usually subcooled. A decline in subcool indicates an imminent loss of seal, and can be alarmed or used as an override control. One thing to watch out for is that the loss of subcool can proceed rapidly, with the seal lost before the corrective action is taken. Another solution is adding a steam trap between the reboiler and the control valve. For as long as it passes condensate, the trap will have no effect. Once the seal is lost, the trap will prevent the steam from blowing into the condensate header. The downside of this approach is that when the trap blocks steam, further opening of the valve has no effect on anything [3], and the controller will tend to open the valve widely.

Energy efficiency and capital

The condensate-outlet valve scheme permits the reboiler heating at a higher pressure because it eliminates the pressure drop in the inlet control valve.

This is a major advantage and an overriding consideration

when the reboil is supplied by refrigerant vapor. Refrigeration-compressor interstage pressures often “ride” on the reboiler condensing pressure, set to provide the desired reboiler heat duty. For instance, if satisfactory condensation can be provided by condensing propylene refrigerant at 20°F, with a scheme like that of Figure 1b, it needs to be compressed to 70 psia (saturation pressure at 20°F) and then run into the reboiler. With the vapor inlet valve, it needs to be compressed to a higher pressure — at least 75 psia and most likely 80 psia — to overcome the pressure drop of the valve. This means higher compressor power consumption and a larger compressor, a major increase in both energy and capital costs, which does not pay out. So almost all refrigerated reboilers use a condensate-outlet valve scheme. The exception is when the compressor interstage pressures are set by alternative criteria, and there is enough pressure to overcome the reboiler-inlet-control-valve pressure drop without increasing compressor energy consumption or size.

Similar considerations apply when reboil is supplied by condensing overhead from the same or a different tower. If from the same tower, the overhead needs to be compressed (a heat-pumped tower), in which case, the reboiler inlet control valve will increase the compressor power consumption and size. If from a different tower, the pressure drop across the inlet control valve will either reduce the reboiler ΔT or force higher pressure operation in the tower whose overhead is condensed, in turn increasing its reflux and reboil requirements. So almost all schemes that heat one tower with the overheads of the same or another tower use the condensate outlet valve scheme.

With steam-heated reboilers, the steam supply pressures are normally set to suit the boilers or turbines rather than the reboilers, and the pressure differences between adjacent supply pressures are generally high. Sufficient pressure difference is usually available between the steam supply pressure and the steam pressure required at a given reboiler, and the difference can be utilized for regu-

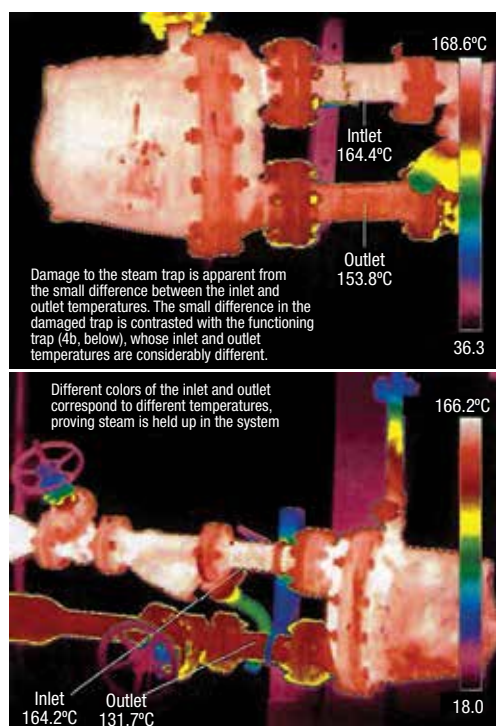


FIGURE 4. The images show thermal scans of steam traps. In 4a, the trap is passing steam, so a small difference between inlet and outlet temperatures is observed. In 4b, the properly functioning steam trap shows its condensate is significantly cooler than the steam (from Ref. 31, reprinted with permission, courtesy of AIChE)

lating the inlet valve. Energy is saved by the condensate-outlet scheme only when eliminating the inlet-valve pressure drop allows stepping down the steam supply pressure. Since this is infrequently the case, the vapor inlet scheme remains competitive in steam-heated reboilers. One uncommon situation where the condensate valve scheme wins is with tower-bottom temperatures so high that ΔT is limited, even at the highest available steam pressure.

The capital costs of the inlet valve scheme tend to be higher [6, 13] because the smaller ΔT generally increases exchanger area to a greater extent than flooding some of the tube surface. The area difference appears to be particularly high when turndown ratios are high or when heating-medium pressures are near critical [6]. In addition, the condensate-outlet scheme uses a smaller control valve.

Fouling, corrosion, thermal stress

In steam-heated reboilers, the inlet valve scheme (Figure 1a) condenses steam at lower pressures and temperatures than the outlet valve scheme (Figure 1b). This reduces the reboiler tube-wall temperatures and suppresses reboiler fouling (process side) and bottom product degradation. This is a major advantage in systems handling materials that can thermally degrade or polymerize.

For thermally degradable and fouling systems, the reboiler-wall temperature can be further minimized by adding a condensate pump (Figure 3a). The pump permits the reboiler pressure to approach, or even fall below, the condensate header pressure. This minimizes the steam condensation temperature, and in turn, the tube-wall temperature.

Both the reboiler and pump may need to be designed for vacuum. In one such system [7], vacuum was actually observed. To avoid vacuum, the condensate drum can be vented to an atmospheric or a positive pressure header instead of to the reboiler. As the condensate is near its boiling point, enough net positive suction head (NPSH) needs to be provided, which may require elevating the reboiler, or even the tower skirt. A common NPSH for a

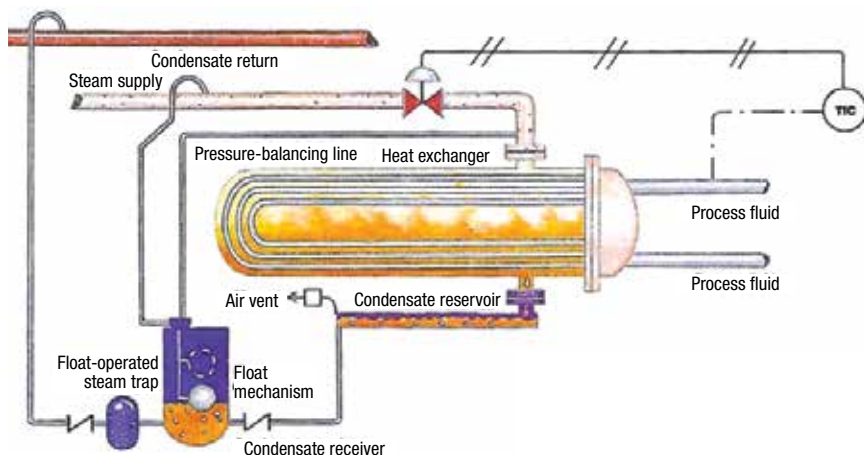


FIGURE 5. This diagram shows the steam-inlet control scheme with a pumping trap and float valve (Reprinted with permission from Ref. 16)

centrifugal condensate pump [14] is 8 ft, but this can be reduced to 2 ft with more expensive special designs. One expert [14] recommends batch pumps powered by gas or steam pressure instead.

Reboiler fouling can be further reduced by recycling some of the condensate to desuperheat the steam (Figure 3b). The condensate recycle line must be adequately engineered, or else it can be more trouble than it is worth. Good engineering requires a temperature control and well-designed injection nozzles when connecting into the steam line to the reboiler, as shown in Figure 3b, as well as a well-designed impingement plate at the reboiler entrance, because condensate drops can be highly erosive to the reboiler tubes near the inlet. The author is familiar with reboilers in polymerizing services where adding the pump of Figure 3b with well-designed condensate recycle lines doubled the run lengths between cleanings [7]. However, the author also encountered cases in which a “shortcut” version of this system, either with no temperature control or with no impingement plate, generated problems that forced discontinuation of the recycle.

Corrosion due to the condensate level maintained in the reboiler often occurs with the condensate valve outlet scheme (Figure 1b). Although condensate is pure water, it becomes very acidic when CO_2 and other gases in the steam dissolve in it. Steam supplied to a reboiler contains various amounts of CO_2 , originating

from decomposition of residual carbonates in the boiler feedwater. In a vertical reboiler, the CO_2 accumulates near the top of the shell from where it can be vented. However, in horizontal reboilers, the CO_2 will accumulate underneath the partition baffle [11, 12], and is absorbed by the condensate near the steam-condensate interface [14]. This will form corrosive carbonic acid. In several reported cases [11, 14], a rust layer on the steam side of the reboiler showed the level at which steam condensate usually ran. A small, continuous bleed from under the partition baffle or corrosion inhibitors can minimize this corrosion.

In horizontal thermosiphons reboilers using the condensate outlet valve control (Figure 1b), subcooled condensate is a short vertical distance away from condensing steam. When the difference between the condensation and tower-bottom temperatures is large, the subcool can be large (even more than 100°F). The wall submerged in the subcooled liquid can be much colder than the wall where the steam condenses. This generates tremendous thermal stresses at the channel head. These stresses are further aggravated when the liquid level ascends or descends — cold sections quickly heat up as the condensate level is reduced or hot sections quickly cool down as the level increases. These thermal stresses often cause leakage at the channel head to the tubesheet gasket [14, 17, 18]. The author and others [12, 17] are familiar with a number of cases where this mechanism caused severe channel-head leaks.

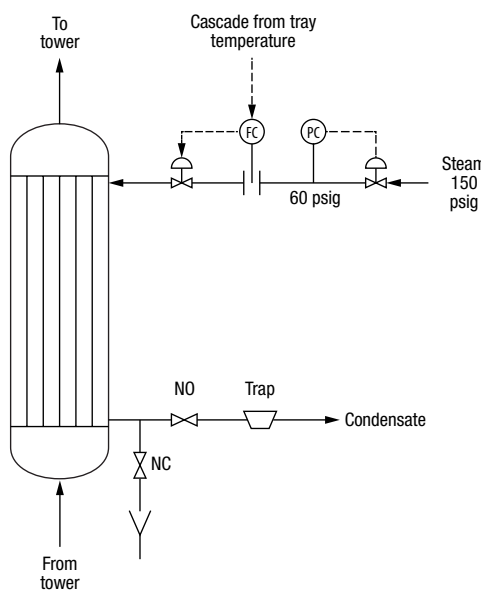


FIGURE 6. The steam-inlet control scheme is shown with a pressure regulator

tions (smallest pressure drop) [13, 14, 19].

Steam traps are some of the least reliable items in process plants. They are prone to plug or stick wide open. A stuck-open steam trap does not only waste steam, but it can also blow the condensate seal, causing a drop in heat transfer, as described earlier. The use of a steam trap is a disadvantage for the inlet-valve scheme. Figure 4 shows two steam traps, one adequately operating, the other passing steam. A condition-monitoring program for the steam trap population at one process plant [20] showed only 48% to be operating well, while 5% of the traps were blowing steam, 13% were leaking, 7% were blocked, 12% were at low temperature, and 15% were at unknown conditions. Regular condition-monitoring programs have been effective for improving steam trap reliability [20, 21]. Ref. 19 provides a detailed description of reliability issues with steam traps.

Steam locking occurs when steam collects in the line between the reboiler condensate outlet and the trap, filling the trap and preventing it from opening [19]. Steam locking can be problematic when the line from the reboiler to the trap is long, or contains many bends, or rises vertically. This is an uncommon mode of trap failure in reboilers.

The vapor inlet schemes in Figure 3a (without the pump) or 3c avoids the trap problems. The scheme in Figure 3c is more costly, but also offers flexibility to deal with the problem described in the next section. A cost-saving variation of the Figure 3c scheme, suitable for in-shell condensation, omits the drum and mounts the level control directly on the reboiler.

Startup and low-rate operation issues with the vapor-inlet valve

The vapor inlet scheme is notoriously troublesome when the reboiler is over-surfaced (for example, over-designed, or during initial operation after turnaround). At startup and low rates, Q is low; and at startup, the tubes are clean, so U is high. With this scheme, the full exchanger area A

Steam traps

The steam trap with the inlet-valve scheme (Figure 1a) needs to be of adequate capacity to handle the condensate flow both under maximum-flow conditions (relatively high pressure drop) and minimum-pressure conditions

is used. To satisfy Equation (1), ΔT needs to be reduced, so the inlet control valve closes and lowers the condensing pressure. If the condensing pressure falls below the condensate header pressure, it will be impossible to remove the condensate, a condition referred to as “stall” [13, 16, 17, 19, 22,]. Some condensate will be sucked back from the condensate header and will flood some of the tube surface, reducing the condensation area A , and raising the condensation pressure. This will continue until the reboiler pressure exceeds the condensate header pressure, and forward flow of condensate from the reboiler to the header is resumed. A new equilibrium is established, with liquid level in the reboiler condensing side.

The point at which condensate will start backing up can be calculated using a procedure similar to that in Refs. 13, 15 and 16. A good field method to evaluate the stall point is by conducting a pressure survey. If stalled, the pressure in the reboiler will be much the same as the pressure in the condensate header at the discharge point. Make sure to account for the static head as the condensate rises to the header.

With reboiler tubes partially flooded, variations in steam flow to the reboiler will affect both the reboiler ΔT and the fraction of tube surface covered by condensate. The ΔT will change instantaneously, but the area will change after a time lag. These two changes often interact, giving rise to heat-input swings and erratic (or at best, slug-

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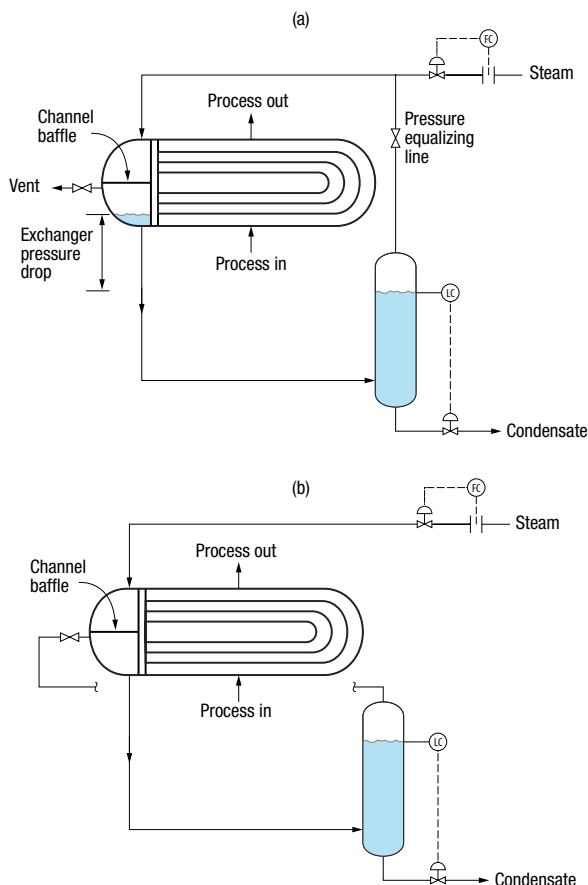


FIGURE 7. These diagrams show the steam-inlet control scheme with a horizontal reboiler and a condensate pot. In 7a, an equalizing line from steam inlet is shown. 7b has an equalizing line from below the partition baffle

gish) response. The steam trap will offer little to assist with the control of the condensate level. Further, if the reboiler load changes are sudden, the above-mentioned equilibrium will be difficult to establish or sustain. Instead, cycling may develop, with the control valve hunting as exchanger surface is covered and uncovered [2,3,7,12,16,18]. Other incidents of such cycling have been reported [7,11,12]. This cycling causes swings in the reboiler duty and column vapor rate, as well as backflow from the condensate header, banging and thumping noises, hammering and tube failure. The trapped condensate in horizontal reboilers can be corrosive, as described earlier. As the condensate level inside the reboiler swings, the temperatures of several tubes swing between that of the hot steam and that of the cold condensate [17], resulting in large thermal stresses and mechanical damage [2,14,17] to the tubes.

To overcome these problems, the steam trap in Figure 1a is often re-

placed by a condensate pot and a pump (Figure 3a), or by a level condensate pot (Figure 3c), as described earlier. By varying the level control setpoint, in Figure 3c, the exposed tube surface in the reboiler can be adjusted so that the reboiler operates at a pressure high enough to ensure condensate removal at all times without a pump. The bottom of this drum should be located below the bottom of the condensing side of the reboiler [23]. Otherwise, “dry” reboiler operation at high rates will not be possible, and reboiler capacity will be reduced.

It is important to properly design and operate the condensate pot. In one case history [15], a column horizontal pre-heater equipped with a steam-inlet control scheme and with a condensate pot (no pump) experienced condensate removal problems upon turndown. In this case history, it was not stated whether the Figure 3a or 3c arrangement was used. Arrangement 3a needs the pump for avoiding this type of problem. Arrangement 3c needs a sufficiently tall condensate pot, with liquid levels that can rise above at least a large portion of the tube area, and adequate operation of the level controller at turndown. The author suspects that in this case, one of these needs was not fulfilled. In another case [24], the condensate pot was integral with the reboiler, no pump. At 50% of the design rates, the level in the pot rose above 100% with the level valve wide open, and there was a problem with removing the condensate. At the design rates, both the reboiler and condensate pot operated as intended.

Several successful applications of the condensate pot techniques above have been reported [2,7,25]. In one of these, the condensate pot was omitted and the level control was directly

on the reboiler. In another [7], a condensate drum low-pressure override cascading onto the condensate-drum level control, prevented the drum pressure from falling below the condensate header pressure. Sometimes, self-priming condensate pumps without condensate pots [25] or pumping traps [16] are installed in the Figure 3a scheme. Three success stories with these solutions have been reported [7]. Another alternative to both of these schemes is to convert to the condensate outlet scheme (Figure 1b). This too has been successfully implemented [7], but has its own issues, as described in this article.

Figure 5 shows a typical pumping trap system utilizing the steam supply to the reboiler [16]. During normal operation, the pressure balancing line is open, and the steam trap removes the condensate. Should stalling occur, the condensate level and float will rise. When the float reaches its maximum travel, it will trip the pressure balance line shut and the line to the steam supply open. The supply-pressure steam will push the condensate into the header. The level and float in the condensate pot will decrease. Upon reaching minimum travel, the float will trip the line to the steam supply shut and re-open the pressure balancing line. A check valve between the reboiler and the drum prevents condensate backflow when the pot is pressurized, and a check valve downstream of the trap prevents massive backflow of condensate during the low-pressure part of the cycle. The success of the pumping trap method depends on the reliability of the two check valves. A reservoir is often provided between the reboiler and drum to prevent reboiler flooding when the pot is pressurized.

A shortcut solution successfully implemented during startups and short (or even longer) periods of low-rate operation, is to open the steam trap manual bypass, and drain the condensate to deck or to the sewer [7, 12, 22,]. Despite its success in solving the problem, this solution should generally be avoided. Besides wasting steam and water, the hot condensate vaporizes hydrocarbons or other volatile materials in the sewer system, potentially causing

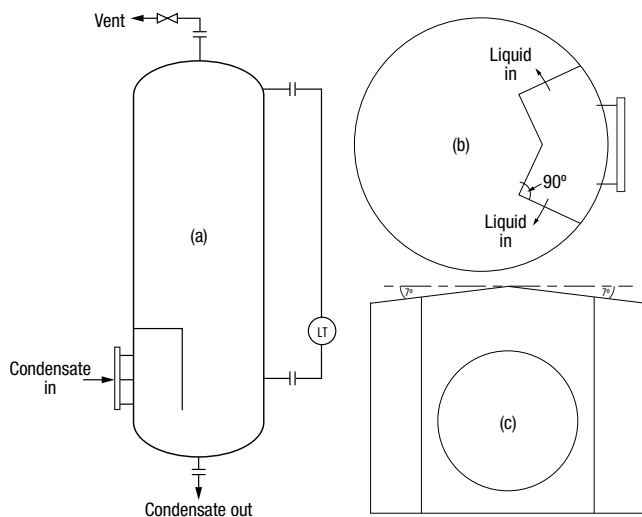


FIGURE 8. These diagrams show a condensate pot with a channel baffle directing the subcooled condensate away from the pot liquid surface. In 8a, it is at elevation; 8b shows the view from the top of the channel baffle; and 8c depicts the view from the inlet nozzle

an environmental issue and even a safety issue. Some plants completely disallow this practice. In other plants, the sewer system may be free of volatiles, in which case, there is neither an environmental nor a safety issue, and this practice is accepted.

Another shortcut solution in a tower that has a spare reboiler [7] is to start the tower up using a fouled reboiler. Once the tower reaches full rates, the clean reboiler is put into operation and the fouled one cleaned. Along similar lines, injecting nitrogen into the reboiler to lower the heat-transfer coefficient has been successful, but in at least one case, some nitrogen and a small amount of oxygen ended up in the condensate and caused major problems in the deaerator.

The vapor inlet scheme may also be troublesome when there is a small pressure difference between the reboiler heating medium and the condensate header (for example, with steam reboilers using 15- to 35-psig steam). The problem is identical to that described above, but it is caused by insufficient ΔP rather than by oversizing, low rates or clean surface. In this case, the above solutions (except the Figure 3c scheme) will also apply. In two different kettle reboilers [17, 22], adding a condensate pump drawing directly from the kettle draw compartment solved such a problem. One expert [18] prefers using the Figure 2b scheme when the ΔP is small.

Critical flow issues

Tuning with the vapor-inlet valve scheme can be troublesome when flow across the valve changes from noncritical to critical upon reboiler turndown [4, 26]. As boilup rate falls, so does the pressure downstream of the valve. When the ratio of upstream to downstream pressure exceeds a critical value, critical flow is established through the valve, where the downstream pressure no longer affects the vapor flowrate. The controller dynamics are different under critical and noncritical flow. A loop tuned for noncritical flow tends to be unstable when flow becomes critical, while a loop tuned for critical flow tends to be

sluggish when flow becomes noncritical [26].

It is best to design the system to operate over its normal range in one flow regime or another. A level condensate seal pot (Figure 3c) can keep up the downstream pressure during turned-down conditions, thereby avoiding this problem. Alternatively, installing a pressure regulator upstream of the flow controller (Figure 6) will lower the pressure upstream of the inlet valve. Both techniques also minimize valve erosion at high pressure drops. The author is familiar with several pressure-regulator systems that have worked very well.

Tube leaks

In many cases, small tube leaks from the heating side (typically steam) to the process side can be tolerated, but even a small leak from the process side to the heating side cannot. In others, the converse applies. When choosing the preferred reboiler control scheme, the possibility of a tube leak must be considered.

With the valve in the condensate outlet, the pressures on the heating and process side are fixed and known, so the leak direction is usually known. However, the quantity leaking will depend on the degree to which the hole is submerged. If the leak is from the heating side above the liquid level, it will be mostly vapor, and the quantity leaking will be small, due to its low density. On the other hand, if the leak is below the liquid level, it will be liquid, and

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TABLE 1. STRENGTHS AND WEAKNESSES OF THE VAPOR-INLET AND CONDENSATE-OUTLET CONTROL VALVE SCHEMES

Item	Vapor-inlet valve Scheme 1a, Figure 1a	Condensate-outlet valve Scheme 1b	Comment
Variable changed	ΔT	A	
Condensate at outlet	Boiling point	Subcooled	
Dynamic response	Superior, fast	Slow	Difference small when tower time constant is large
Loss of condensate seal	Seldom an issue	Problematic unless using condensate pot	Not a major issue
Energy efficiency	Only good when can use same heat medium as 1b	Superior, critical with refrigerant and heat integrated systems and some steam systems	Major advantage for 1b in relevant applications
Capital cost	Higher	Lower	Not a major issue
Fouling, degradation on process side	Superior, especially with condensate pot as in Figures 3a, b,	Inferior	
Corrosion, thermal stresses	Usually not troublesome	Problematic with horizontal reboilers	
Steam trap	Problematic	Seldom an issue	Can be easily solved with condensate pot
Startup and low-rate operation	Can be very troublesome	Seldom troublesome	Can be easily solved with condensate pot
Critical flow across valve	Can be an issue at turndown	Seldom an issue	Can be readily solved
Tube leaks	Direction often unpredictable	Direction predictable, quantity not	Major advantage for 1b in relevant applications
Condensate compatibility	Boiling point condensate	Subcooled condensate	

its quantity can be several orders of magnitude larger (liquids have higher density). This can make all the difference between a minor, almost unnoticeable, leak and one that leaks many gallons of liquid.

With the valve in the vapor or steam to the reboiler, it is often difficult to tell which way the leak will go. At high rates, the heating-side pressure may exceed that on the process side, while at turndown, or when a reboiler is excessively surfaced, the pressure on the heating side may fall below the process pressure. When the tower trays are replaced by packings (lower pressure drop), the process-side pressure may fall below the heating-side pressure. The author is familiar with a tower where leaks normally proceeded from the steam side to the process side (these could be tolerated). However, when a new, larger reboiler was installed, the next leak reversed itself, the process chemical entered the steam system and was hydrolyzed into acidic components that corroded the steam/condensate system.

Flashing and hammering

The inlet valve scheme (Figure 1a) releases boiling point condensate into the condensate header. This condensate can be at higher pressure than that of the header, which will generate flash steam. The condensate drain line downstream of the trap or control valve must take this flashing into account [12,14,17]. A line undersized for flashing can lead to premature stall in the reboiler. One case [12] was reported of condensate backup in the reboiler due to flashing in the condensate line that was unaccounted for. That reboiler could only be operated when the condensate was diverted to the sewer (this is not a good practice, as mentioned above). The flashing checks should take into account any rise in elevation — the condensate may be water when it exits the trap, but may flash upon pressure reduction as it rises up a vertical line. Several such cases were reported [12]. Lieberman [12] mentions two solutions that effectively solve the problem of stalling due to flashing at

elevation: enlarging the line size (best solution), or injecting cold water at the base of the riser (this may cause a water-quality problem).

Hammering occurs when flash steam due to line flashing, blowing the condensate seal, or a steam trap stuck open, contacts subcooled condensate from the header or from another source discharging into the header.

The inlet-valve scheme is compatible with a condensate system that contains boiling point condensate. If sent into a condensate system containing significantly subcooled condensate, the flash steam from the reboiler condensate may hammer as it collapses onto the subcooled header condensate.

Conversely, the condensate outlet valve scheme (Figures 1b and 2) releases subcooled condensate into the condensate header. It is compatible with a condensate system that contains subcooled condensate. If sent into a condensate system containing boiling point condensate and flash steam, the flash steam may hammer as it collapses onto the subcooled reboiler condensate. Commonly, a header that picks up condensate from steam traps will contain flash steam, and will hammer when contacting the subcooled condensate. One clever technique that was successful in alleviating the hammering [12] in at least one case is inserting a cone-shape insert with orifice holes into the condensate piping. This insert acts as a dampening brake on the accelerating water. The more restrictive the insert, the better the dampening but also the higher its pressure drop and the greater risk of its plugging.

Condensate accumulation

With the condensate outlet scheme, condensate accumulation in horizontal shells at turned-down conditions can flood most of the exchanger baffle windows and restrict vapor passage through the window. This may result in liquid hammering [27].

It has been suggested [18] that a level indication of the condensate in the reboiler shell is useful for the operator. The arrangements shown in Figures 1–3 can be designed to provide this.

A flexible system

With a condensate pot, a flexible system can be devised. One can hook the steam control either to the valve in the steam line or to the level valve in the condensate line. The condensate drum needs to be designed so that it is about as tall as the reboiler and ends a few feet below the reboiler.

Condensate pots

Figures 2 and 3 depict different condensate pot arrangements. Some of the main considerations in their design and operation are the following:

Consideration No. 1. Condensate drums may be vertical or horizontal.

Consideration No. 2. A pressure-equalizing line must be provided. This is a small line (often 1-in. dia.) connecting the top of the reboiler with the top of the condensate pot. Without this line, it will be impossible to maintain a steady pressure and level in the condensate pot. Setting the equalizing line must consider the pressure balance. One horizontal thermosiphon reboiler (Figure 7a) experienced deficient steam flow, leading to poor stripping in the tower [28]. The measured steam-side pressure drop was 3 ft of water, making the condensate level in the reboiler at least 3 ft higher than in the condensate pot. This was enough to flood some of the reboiler tubes. The flooded height increases

with the pressure drop, which in turn increases with the square of the steam flowrate. With horizontal thermosiphons, even a short submerged height can lose considerable condensation area. It was recommended [12,28] to connect the equalizing line to the valve immediately below the lower pass partition baffle (Figure 7b). Engineers wishing to use the valve in the steam line (Figure 7a) should closely watch the pressure balance and pot level and elevation [3].

Consideration No. 3. In the Figure 2 and Figure 3c arrangements, the condensate in the condensate pot is subcooled. The subcooled condensate has a vapor pressure that may be an order of magnitude lower than the steam pressure. If this subcooled condensate reaches the liquid surface in the pot, the drum pressure will dive, causing a rush of vapor from the equalizing line, which the equalizing line may not be able to supply. Steam from the equalizing line may collapse onto the subcooled surface, causing instability, inability to control the condensate pot level and hammering. One such case study was described [29] and the author is familiar with others.

To prevent this, it is important to feed the subcooled liquid near the bottom of the drum or into the drum outlet line and to prevent it from rising to the surface. Figure 8 shows

the design and shielding baffle [29] used to solve the hammering and instability issue described above.

Consideration No. 4. Arrangements 2a, 2b, and 3c require a sufficient surge volume in the condensate pot in order to prevent reboiler level variations from flooding or draining the pot. In arrangement 3a (with or without a pump) and 3b, a lower volume is adequate. Here, the main consideration is providing sufficient seal height to avoid vapor breakthrough. In this arrangement, liquid level is kept below the reboiler bottom.

Consideration No. 5. Bertram [30] has discussed sizing condensate pots. The paper presents a sizing chart and a few examples, but no firm guidelines. Based on the author's interpretation [7] of the information presented by Bertram, the following guidelines can be inferred: *For all arrangements depicted in Figures 2 and 3):*

- The maximum recommended liquid velocity through a vertical drum is generally a function of the condensate valve size, as shown in the box below:

Condensate control valve size, in.	Maximum liquid velocity, gal/min per ft ²
1	25
1½–3	37
>4	50

- Allow at least 6 in. above the upper-level nozzle and below the lower-level nozzle to mechanically accommodate the nozzles
- Allow a vapor space of 12 to 24 in. between the highest liquid level expected and the upper level nozzle. This space serves as a safety margin and could help in accommodating a high-level alarm

For a large condensate pots (Figures 2 and 3c only):

- Allow at least 12 in., or 20% of the total range of the level instrument (whichever is greater) between the bottom of the tubesheet and the lower nozzle
- Increase drum size to provide the required surge volume in the drum as per consideration 4 above

For small condensate pots (Figures 3a and 3b only)

- A height of 32 in. is usually a satisfactory range for level control.
- A drum about 4 ft high, with the midpoint about the same height as the bottom reboiler tubesheet, is often satisfactory [18]

For a level condensate pot (Figure 3c only; author's guideline):

Set the highest liquid level to match the expected liquid level in the reboiler under the most severe turn-down conditions required. Keep in mind that these may occur under startup conditions, when the reboiler is clean and the heat-transfer coefficient is high.

Consideration No. 6. In steam reboilers, a small atmospheric vent should be provided on top of the condensate drum and always left cracked open [18] (except when steam-chest pressure dips below atmospheric pressure). This will prevent noncondensable gas buildup, which may reduce reboiler efficiency; if CO₂ is one of the noncondensable gases, it can also cause corrosion. Similarly, when a heating medium other than steam is used, adequate condensate drum venting is required.

Strengths and weaknesses of each scheme

Table 1 provides a summary of the strengths and weaknesses of the two schemes. In the table, blue print

represents major strengths, while red points out major weaknesses. Scheme 1a has major advantages of fast dynamic response and handling fouling and thermally degradable systems. The advantage in thermally degradable and fouling systems can be enhanced with judicious condensate-pot and pumped-condensate design. Its drawbacks are the steam trap and the ability of getting rid of the condensate at turned-down operation, but both can be overcome with a good condensate-pot design.

Scheme 1b offers the energy-efficiency advantage, which is a controlling consideration when the reboiler is heated with refrigerant vapor, or with the overhead of another tower, or when using Scheme 1a will require increasing the steam pressure. Scheme 1b can be problematic with corrosion and tube leaks in horizontal reboilers, especially with high subcools.

The direction of a possible tube leak and its impact needs to be considered. With the 1a scheme, the direction is not always predictable, which may be a major issue. With the 1b scheme, a small tube hole in the submerged portion of the tubes can leak gallons of liquid instead of a tiny amount of vapor. Last, but not least, compatibility with the condensate header needs be considered to minimize hammering.

If after reading this, you are still not sure which scheme to prefer, this article has good news for you. With a condensate pot, a flexible system can be devised. One can hook the steam control either to the valve in the steam line or to the level valve in the condensate line. The condensate drum needs to be designed so that it is about as tall as the reboiler and ends a few feet below the reboiler. With a well-designed flexible system, you can try them both out, and choose the one that works better for your reboiler. ■

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Seal Considerations to Reduce Fugitive Emissions

By understanding the basics of industry standards, such as API 682, plants can make great strides in controlling fugitive emissions related to equipment seals

**Brian Kalfrin
and Neil Slater**
John Crane, Inc.

IN BRIEF

API 682 OVERVIEW

API PLAN 52

API PLAN 72

API PLAN 75

API PLAN 76

CONTACTING AND
NON-CONTACTING

Chemicals that unintentionally leak from equipment into the atmosphere are known as fugitive emissions. These gases and vapors include volatile organic compounds (VOCs) and greenhouse gases, such as carbon dioxide, methane and nitrous oxide.

In 1963, the U.S. Environmental Protection Agency's (EPA; Washington, D.C.; www.epa.gov) Clean Air Act set guidelines regulating these emissions from industrial facilities into the atmosphere. Additionally, standards organizations, including the American Petroleum Institute (API; Washington, D.C.; www.api.org), have established test standards.

The guidelines set forth by the EPA, API and other organizations are intended to help lower the negative impacts of fugitive emissions on the environment and human health. Even so, fugitive emissions remain a concern and can take a significant financial toll on manufacturers in the chemical process industries (CPI), in terms of lost product, environmental remediation costs, unplanned maintenance and downtime.

Fugitive emissions can leak from various machinery sources, including valves, flanges and fittings. However, a sometimes overlooked — but nonetheless important — source of fugitive emissions can be linked to seals installed in pressurized, rotating equipment, including pumps and compressors (Figure 1). Seals are mainstays in chemical plants and petroleum refineries, and are designed to help prevent leaks and contain pressure within pumps and other rotating machinery.

While seals are intended to address fugitive emissions, one size does not fit all. This article addresses basic seal considerations for reducing the risks associated with fugitive emissions, beginning with API 682 (Pumps — Shaft Sealing Systems for Centrifugal and Rotary Pumps) and its corresponding piping plans. API 682 is the primary industry standard for hydrocarbon sealing in petroleum refineries and petrochemical plants, cover-



FIGURE 1. Pumps in industrial plants are an often overlooked source of fugitive emissions

ing numerous arrangements and configurations for single- and dual-seal installations. The discussions in this article mainly pertain to reducing fugitive emissions with dual-seal arrangements (Figure 2), which comprise two primary seals separated by a barrier or buffer fluid.

API 682 overview

In 1994, the first edition of API 682 was published. Now in its fourth edition, API 682 sets the benchmark for hydrocarbon sealing in petroleum refineries and petrochemical plants. The standard not only dictates pump-seal space-availability requirements, but also covers the seal types, arrangements, materials, test criteria and even their support systems — as well as the technological performance criteria. The mission statement for API 682 states that it “is designed to default to the equipment types most commonly supplied that have a high probability of meeting the

objective of at least three years of uninterrupted service while complying with emissions regulations.” Additionally, within the broader API 682 standard, the API Piping Plans for dual seals are primarily segregated into two varieties: unpressurized and pressurized.

For discussion purposes here, the focus will be on dual unpressurized piping plans for API Arrangement 2 seals. Arrangement 2 seals are defined as those where the buffer media pressure is lower than the seal-chamber pressure (dual unpressurized seals). The prominent piping plans for Arrangement 2 seals are API Plans 52, 72, 75 and 76. It is the expectation with any Arrangement 2 seal that the equipment be shut down and depressurized within eight hours of detected inner-seal failure.

API Plan 52

API Plan 52 is used solely for wetted contacting containment seals for both non-volatile and volatile processes. These seals require a liquid buffer system for support. An external reservoir is used to provide buffer fluid to an unpressurized dual seal's outer seal. An internal pumping ring maintains circulation between the reservoir and outer seal. Also, the reservoir usually vents to a vapor-recovery system.

Advantages of API Plan 52 layouts include reduced overall leakage into the atmosphere. It also provides redundancy in the event of inner-seal



FIGURE 2. A dual-seal arrangement provides many configuration options to help reduce fugitive emissions from rotating machinery

failure. Potential solids or salts are kept in solution or suspension and the outer seal performance (visual or instrumented) is continuously monitored. However, with this configuration the buffer fluid is contaminated with process fluid. Therefore, in some processes it becomes a hazardous fluid, so disposal and personnel exposure concerns must be addressed. The buffer fluid may also be completely displaced by process fluid during inner-seal upsets, causing the containment seal to run dry and experience damage. Buffer-fluid cooling is often required to provide a more conducive environment for the containment seal faces. Operators are notified by an alarm indicating either high level or high pressure within the reservoir in the event of an inner-seal failure.

API Plan 72

Plan 72 is used with dry-running containment seals. Dry-running seals can be either contacting or non-contacting. Plan 72 specifies a gas buffer, usually nitrogen, which is used to sweep the containment cavity and push vapor leakage from the inner seal to vapor recovery or flare system. Plan 72 is used often in conjunction with either API Plan 75 or 76.

Plan 72 supplies a buffer gas from a low-pressure purge injected into the outer seal cavity, and can support both contacting and non-contacting containment seals. An uninterrupted flow of clean nitrogen or other dry gas is commonly used as a supply of inert-gas buffer. Low-pressure purge gas is injected into the outer-seal cavity. The gas-purge supply is introduced close to the outer-seal faces, while the vent and drain are positioned away from seal faces. API Plan 72 is effective in providing some cooling to the outer-seal cavity with contacting containment seals. It minimizes inner-seal air exposure and leakage to the atmosphere, as well as constantly sweeping inner-seal leakage to flare. A control panel may be installed away from equipment, because the system is not limited by flow induced from an internal circulation device, such as a pumping ring.



FIGURE 3. Non-contacting seals are designed to minimize heat generation due to friction, meaning that they can withstand higher pressures than contacting seal arrangements

API Plan 75

API Plan 75 provides management of leakage of condensable gases. It is intended for use when the process sealed by the inner seal condenses at lower temperatures or is mostly in liquid form. The seal drain is located at the bottom of the outer-seal gland and routed to a reservoir below the seal. Liquid leakage is collected, and the gaseous portion is routed to the flare. This plan can offer lower initial costs when compared to Plan 52. The system can be designed to dispose of the liquid collected without operator exposure. A pressure-containing reservoir, as well as monitoring and maintenance, are required with API Plan 75.

API Plan 76

API Plan 76 is intended for use when the process sealed by the inner seal will not condense at lower temperatures or pressures. A vent is located at the top of the outer-seal gland and is routed to flare through an orifice. API 682 requires a minimum orifice diameter of 0.125 in. (3 mm) — but smaller sizes may be necessary to provide a realistic leakage-alarm point. API Plan 76 offers low maintenance and installation costs when compared with other dual-seal piping plans. However, it may be difficult to detect if liquids are present in the system. Premature wear of dry-running containment-seal faces may be encountered if inner-seal leakage contains components that condense.

Contacting and non-contacting

Although the intent of the sealing applications from the first to the fourth editions of API 682 have been largely consistent, newer materials and technologies have been incorporated into the later revisions.

Dry-contacting containment-seal designs operate in gaseous environments and use a limited amount of fluid within the seal interface film. To compensate for the lack of fluid at the sealing interface, seal manufacturers may use specially formulated grades of carbon and optimized spring loads to control face wear and interface temperatures.

Contacting dry-running containment seals provide the lowest leakage levels when sealing vapor or liquid leakage from the inner seal, but can be pressure limited (based on face wear). These seals have a finite life based on the contacting nature of the seal faces. Testing protocols should be implemented to monitor the condition of the containment seal. They are typically suitable for continuous operation in a gaseous environment with excursions in the flare or vapor-recovery system up to 40 psig, in accordance with API 682 criteria.

These seals can be either O-ring pusher mechanical-seal designs or dry-running metal-bellows configurations. Both variants are used to provide emissions control from low-specific-gravity fluids and other VOCs when used in conjunction

with a suitable inner-seal design.

Non-contacting, dry-running containment seals (Figure 3) are seals where the faces are designed to intentionally create aerodynamic or hydrodynamic separating forces to sustain and maintain a specific separation gap. Non-contacting containment seals use deliberate recesses or grooves to generate

hydrodynamic lift where the faces ride on a gas film during normal operation. The generated film stiffness produced from the face features provides the face lubrication and ensures that there is no face contact while in operation. The non-contacting operation of the faces eliminates rubbing frictional heat generation, allowing non-contact-



FIGURE 4. Gas-lubricated, non-contacting secondary containment seals, often applied as a component of a multiple seal cartridge, are resilient in challenging process conditions, including in the presence of low-dewpoint gases and high pressure differentials

ing containment seals to withstand much higher pressures and higher speeds than contacting containment-seal designs.

Non-contacting dry-running containment seals are the default option in API 682 when considering a dry containment-seal system (no liquid buffer). They have a lower wear rate in operation and are more tolerant of low-dewpoint buffer gases, higher

surface speeds and pressure differentials (Figure 4).

These seals are advantageous when compared to dry-contacting containment seals in that the deliberate face separation insulates the seal from accelerated wear due to pressure excursions in the flare or vapor-recovery system. They can be instrumented to monitor temperature changes within the seal

and provide an additional indication of elevated inner-seal leakage. Furthermore, they offer an extremely durable seal design and provide low cost of operation and ownership.

These sealing arrangements are among the many presented in API 682. Since the introduction of Plans 52, 72, 75 and 76 in early editions of API 682, lessons learned and additional testing activities have yielded a better understanding of the capabilities and limitations of some seal-support systems. Continued collaboration between seal manufacturers, end users and engineering contractors will provide the safest, most reliable and cost-effective sealing system for any application. As a result, these companies will continue to make positive impacts on the environment by reducing fugitive emissions. They will also reduce product waste, environmental remediation costs, unplanned maintenance and downtime. ■

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A Simplified Approach to Crystallization Mass Balances

In continuous crystallization, it is often challenging to accurately measure mass flowrates, but the method described here enables a simpler path to a balanced crystallization process

Jan Meijer

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To gain optimal value from industrial crystallization processes, it is clear that understanding specific crystal properties is essential [1], but it is also important to have an accurate picture of the system mass balances. In practice, accurate measurement of mass flowrates in crystallization processes can be quite burdensome, especially at large production plants, which may have less measurement instrumentation installed compared to smaller, research-focused pilot plants. This article presents a simple mass-balance model that provides a basic understanding of evaporative crystallization using six independent equations and seven unknown mass flowrates. Using this model, assessment of just one mass flowrate directly delivers the mass balance of the entire crystallization process.

Overview of crystallization

Figure 1 shows a straightforward model of a continuous crystallization process consisting of one evaporator, as in a mechanical vapor recompression (MVR) plant, or consisting of multiple evaporators in series, as in a multi-effect evaporation (MEE) plant. Corresponding process parameters and nomenclature for this example are given in Table 1. In the model, the distinction between the saturator and evaporators is purely conceptual, as in practice, both process steps are merged. The feed (F) flow is usually slightly unsaturated with respect to the solute at the conditions (such as temperature, pressure and composition) in the last evaporator. Note that feeding may take place randomly to one or more evaporators. The last evaporator is the one from which the (combined) slurry flows to the centrifuge that separates crystals from the mother liquor. In the saturator, only water ($W1$) is evaporated until the feed becomes saturated (SF). Therefore, no crystallization takes place in the saturator.

In the evaporator, water ($W2$) is evaporated, leading to the crystallization of solids (*crystal*) and concurrent formation of a saturated mother liquor (ML) flow. The total flow of water (W) is the sum of $W1$ and $W2$. The solute concentration (C , wt.%) in the feed and its solubility (S , wt.%) in the mother liquor of the last evaporator are

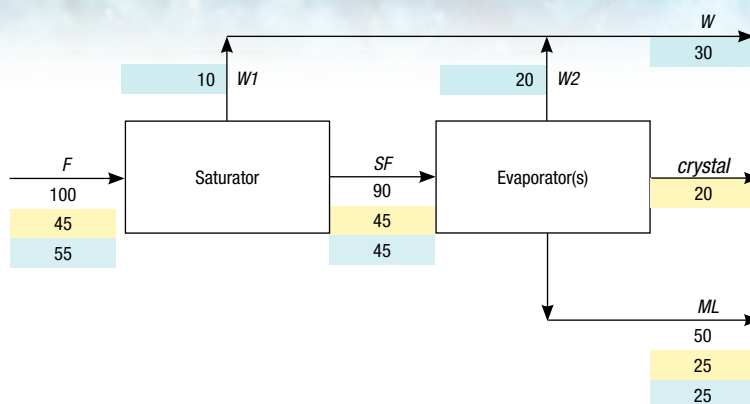


FIGURE 1. This straightforward model of a continuous crystallization process shows mass flows, with the portion of each stream representing water (highlighted blue) and process solute (highlighted yellow). The crystal mass flow indicates the part of the solute that has been turned into solid crystals

usually easily determined analytically and considered to be known. Also considered known is the concentration factor (CF), which is the ratio of the mass flowrate of the feed and the mass flowrate of the mother liquor. In general, CF can almost always be determined via an impurity in the feed that remains dissolved in the mother liquor at crystallization, a so-called marker. Thus, CF is equal to the ratio of the marker concentration in the mother liquor and its concentration in the feed. Note that the measurement unit for the marker concentration must be mass/kg, whereas mass/L is standard for analytical data. Therefore, division by the densities of the feed and mother liquor is required unless these densities are equal. In practice, marker inclusion inside individual crystals is negligible for mass-balance purposes. The following set of equations can now be compiled where all symbols except C , S and CF reflect mass flowrates:

$$\text{Overall mass balance:} \\ F = ML + \text{crystal} + W \quad (1)$$

$$\text{Concentration equation:} \\ F = CF \times ML \quad (2)$$

$$\text{Saturation balance:} \\ F = SF + W1 \quad (3)$$

$$\text{Sub-saturation equation:} \\ SF = C/S \times F \quad (4)$$

TABLE 1. EXAMPLE CALCULATION PARAMETERS FOR AN EVAPORATIVE CRYSTALLIZER

Parameter	Nomenclature	Unit	Example value
Concentration of solute in feed	<i>C</i>	wt. %	45
Solubility of solute in ML at separation temperature	<i>S</i>	wt. %	50
Concentration factor [marker(ML)/marker(F)]	<i>CF</i>	#	2
Feed	<i>F</i>	arbitrary units (a.u.)	100
Water produced from subsaturation of feed	<i>W1</i>	a.u.	10
Saturated feed	<i>SF</i>	a.u.	90
Mother liquor	<i>ML</i>	a.u.	50
Water produced at crystallization	<i>W2</i>	a.u.	20
Total water	<i>W</i>	a.u.	30
Crystal	<i>crystal</i>	a.u.	20
Natural slurry density at evaporator(s)	<i>NSD</i>	wt. %; g%	28.6; 30.8
Mother liquor removal	<i>MLR</i>	a.u.	15
Crystal recycle	<i>cR</i>	a.u.	4
Slurry density at evaporator(s)	<i>SD</i>	wt. %; g%	40.7; 47.3
Crystal recycle fraction	<i>cR#</i>	#	20%
Mother liquor removal fraction	<i>MLR#</i>	#	30%

Water balance:

$$W = W1 + W2 \quad (5)$$

Solubility equation:

$$W2 = (100 - S) / S \times crystal \quad (6)$$

Crystallizer balance:

$$SF = W2 + crystal + ML \quad (7)$$

Equations (1), (3), (5) and (7) are straightforward mass balances. Equations (2), (4) and (6) are concentration-based. Because Equation (7) can be derived from Equations (1), (3) and (5), this equation is not independent and can be used as a check. Mathematical stability demands that $S \neq 0$.

The above equation set consists of six independent equations and seven unknown mass flowrates (*F*, *SF*, *W1*, *W2*, *W*, *crystal* and *ML*). Consequently, only one mass flowrate can be chosen freely and fixes the capacity of the crystallization process. This is fundamental, as after all, the above given set of equations is valid irrespective the measurement unit selected for the mass flows (meaning that ton/s is as justifiable as mg/yr).

If, for example, a feed flowrate of 100 arbitrary units (a.u.) is chosen as in Figure 1, all other mass flows are fixed, assuming that *C*, *S* and *CF* are known. Of course, if preferred, one of the other mass flows can be freely chosen, but then the feed flowrate is fixed.

Consequently, one needs to measure only one mass flowrate to access all other mass flowrates, which can be quite convenient, especially at large production plants. The most suitable mass flowrates to measure are either the condensate (*W*) or the feed (*F*).

Measurement of the *crystal* mass flow or the *ML* mass flow is more difficult, as at the point of separation, some mother liquor remains attached to the crystals, and tiny crystals may persist in the mother liquor.

It is evident that the saturated-feed mass flowrate (*SF*) is technically inaccessible for measurement.

An additional feature of this approach is that measuring two mass flows (for example, *W* and *F*) provides a convenient method to check the performance of the two flowmeters involved. Furthermore, note that *C* can potentially be larger than *S*, resulting in a negative *W1* value.

Natural slurry density

The natural slurry density (*NSD*; wt. %) of a crystallization process is given in Equation (8) below:

$$NSD = 100 \times crystal / (crystal + ML) \quad (8)$$

Substitution and rearrangement using Equations (1) through (8) shows that this *NSD* equation can be converted into

Equation (9):

$$NSD = 100 \times (C \times CF - S) / (C \times CF - S + 100) \quad (9)$$

Equation (9) shows that the natural slurry density is independent of mass flowrate and can easily be calculated from *C*, *S* and *CF*. Also, a simple graph can be constructed that gives *NSD* as a function of *CF*, as shown in Figure 2, whereby $C = S$.

The physical reason for the direct causality between *NSD* and *CF* is due to the evaporation of water, as illustrated in Figure 3. If water evaporates from a saturated solution, both *CF* and *NSD* increase.

Glass and weight percentage

In Table 1, *NSD* is presented one time as a weight percentage (wt. %) and one time as a glass percentage (g%). *NSD* is first defined as wt. % in Equation (8), which is convenient for mass-balance calculations.

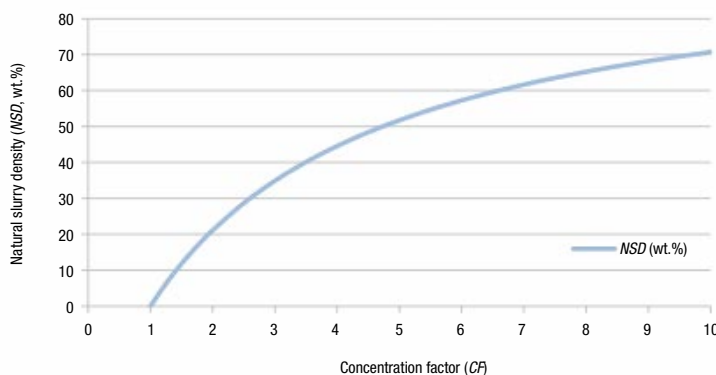


FIGURE 2. Natural slurry density is a function of concentration factor, but is independent of mass flowrate

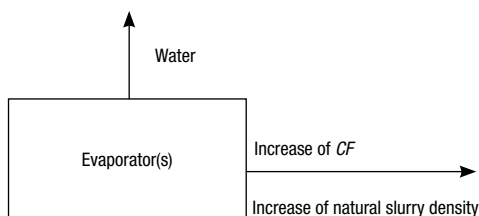


FIGURE 3. Water evaporation is the driving force behind the relationship between natural slurry density and concentration factor (CF)

However, in practice, slurry density is typically determined as g%, using a glass (or plastic) measuring cylinder, as illustrated in Figure 4. To determine slurry density in g%, a crystal slurry is poured into a cylinder and subsequently allowed to settle freely, which lasts ordinarily only a few seconds. Then, g% is calculated as the height of the settled crystal slurry divided by the height of the mother liquor (both measured from the bottom of the cylinder) times 100. Equations (10) and (11) below give the conversion between g% and wt.% units.

$$g\% = \frac{100 \times \text{wt.\%}/\rho_{wb}}{(100 - \text{wt.\%})/\rho_b + \text{wt.\%}/\rho_s} \quad (10)$$

$$\text{wt.\%} = \frac{100 \times g\%/\rho_b}{100/\rho_{wb} + g\%/\rho_b - g\%/\rho_s} \quad (11)$$

In Equations (10) and (11), ρ_s is the crystal density and ρ_b is the density of the mother liquor. The wet bulk density (ρ_{wb}) reflects the mass of only the crystals at 100 g% slurry density, depending on the specific shape of the crystals, among other parameters. For simple, equally sized, cubic crystals at the closest packing density, ρ_{wb} is equal to $\pi/6 \approx 0.5236 \times \rho_s$ [2].

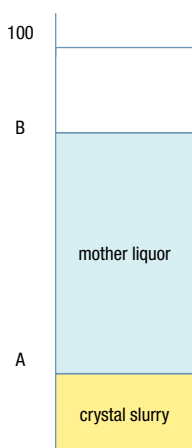
However, in practice, determination of ρ_{wb} is essential, because crystallization almost always results in a specific particle-size distribution (PSD) of the crystals and the closest packing is not reached. The ρ_{wb} at 100 g% actually reflects the loose bulk density — as if no mother liquor is surrounding the submerged crystals.

Changing slurry density

Usually, operational considerations (like clogging) demand that slurry density does not exceed about 30–40 g%, except for elutriation or washing legs, or exits of hydro-cyclones just upstream of centrifuges.

An excessively low slurry density may lead to fine crystals that hamper centrifuging. This shows that slurry density has a profound influence on crystallization, because slurry density determines the crystal surface available for growth (assuming constant PSD). If insufficient crystal surface area is available for growth, supersaturation increases (as evaporation is imposed on the crystallizers) until nucleation occurs.

The effect of slurry density on crystallization is temperature-dependent, because kinetics are much faster at higher temperatures. Consequently, at higher



$$g\% = (A / B) \times 100$$

FIGURE 4. To determine the natural slurry density in glass percentage (g%), crystal slurry is poured into a measuring cylinder and allowed to settle freely. Once settled, the crystal slurry and mother liquor heights are used to determine the glass percentage

temperatures, lower slurry density can be tolerated without detrimental decrease of PSD due to excessive nucleation. Clearly, control of slurry density is essential for any crystallization process. In principle, there are two main methods to decrease slurry density:

- Crystal removal (for example, via a washing leg)
 - Mother liquor recycle (for instance, mother liquor recycled from a cyclone or centrifuge)
- Conversely, there are also two main methods to increase slurry density:
- Crystal recycle (for instance, a more concentrated crystal slurry recycled from a thickener or separator)
 - Mother liquor removal via an annular zone

Slurry density revisited

By definition, the actual slurry density (*SD*, wt.%), including mother liquor removal (or recycle) or crystal recycle (or removal) at the crystallization process is given in Equation (12):

$$SD = 100 \times (crystal + cR) / (crystal + cR + ML - MLR) \quad (12)$$

In this equation, both crystal recycle (*cR*) and mother liquor removal (*MLR*) are defined as positive mass flowrates, similar to *crystal* and *ML* in Table 1. Conversely, crystal removal is defined as negative crystal-recycle mass flowrate, whereas mother-liquor recycle is defined as negative *MLR* mass flowrate.

The *SD* equation above can mathematically be converted by substitution using the set of seven equations given before, and rearrangement, giving Equation (13):

$$SD = \frac{100 \times (C \times CF - S) \times (1 + cR\#)}{(C \times CF - S) \times (1 + cR\#) + 100 \times (1 - MLR\#)} \quad (13)$$

Where:

cR# = crystal recycle fraction (*cR/crystal*)

MLR# = mother-liquor removal fraction (*MLR/ML*)

This last equation shows that the actual slurry density is independent of mass flowrates and can simply be calculated from easily accessible parameters, such as *C*, *S*, *CF*, *cR*# and *MLR*#. Using the values given in Table 1, we see that *cR*# = 0.2 (logged as 20%), and *MLR*# = 0.3 (logged as 30%).

Crystal recycle is typically more effective compared to mother liquor removal, since the *crystal/ML* ratio is most frequently less than 1. The slurry density can be increased, maintaining the same production level, because this production level is determined by the evaporation of water. The slurry density merely reflects the hold-up of crystals in the evaporator, so a slurry den-

sity increase prolongs the mean residence time of the crystals. Finally, a crystal recycle fraction larger than 1 (where crystal recycle is greater than 100%) is not an exceptional condition.

Other crystallization processes

The methodology described in this article is presented for a continuous evaporative crystallization process, but it is equally applicable for a batch evaporative crystallization process by using mass instead of mass flowrate. Furthermore, the method can be applied for cooling, anti-solvent and reaction crystallization processes. Because no solvent is removed (*W* = 0) in these three crystallization methods, *CF* is no longer a free variable and now equals $(100 - S)/(100 - C)$, provided that the following statements are true:

- In anti-solvent crystallization, the concentration in the feed, *C*, must be based on the total mass (or flowrates), so the added anti-solvent mass (or flowrates) should be included
- In reaction crystallization, the concentration in the feed, *C*, is the calculated concentration of the crystallizing component, based on the total mass (or flowrates) of all reactants, after complete conversion due to reaction

Now, the formulas for *NSD* and *SD* can be shortened into Equations (14) and (15), respectively:

$$NSD = 100 \times (C - S) / (100 - S) \quad (14)$$

$$SD = \frac{100 \times (C - S) \times (1 + cR\#)}{(C - S) \times (1 + cR\#) + (100 - C) \times (1 - MLR\#)} \quad (15)$$

From this simple mass-balance approach, assessment of just one mass flow can unlock the mass balance for the entire crystallization process. Furthermore, this approach clarifies that natural slurry density is fixed by concentration factor, solubility in the mother liquor and solute concentration in the feed — not by mass flowrate. Similarly, slurry density is fixed by concentration factor, solubility in the mother liquor and solute concentration of the feed, plus crystal recycle and *ML* removal, and not by mass flowrate. Beyond evaporative crystallization, the methodology presented here is also applicable for cooling, anti-solvent and reaction crystallization processes. ■

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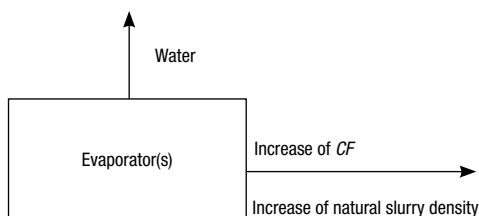


FIGURE 3. Water evaporation is the driving force behind the relationship between natural slurry density and concentration factor (CF)

However, in practice, slurry density is typically determined as g%, using a glass (or plastic) measuring cylinder, as illustrated in Figure 4. To determine slurry density in g%, a crystal slurry is poured into a cylinder and subsequently allowed to settle freely, which lasts ordinarily only a few seconds. Then, g% is calculated as the height of the settled crystal slurry divided by the height of the mother liquor (both measured from the bottom of the cylinder) times 100. Equations (10) and (11) below give the conversion between g% and wt.% units.

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The effect of slurry density on crystallization is temperature-dependent, because kinetics are much faster at higher temperatures. Consequently, at higher

Owning Your Career: Taking a Hard Look at ‘Soft’ Skills

A personal development strategy helps to set engineers up for success in their personal and professional lives

Garrett Forsythe

Operational Excellence Consultant

As chemical engineers, we have been trained to be data-driven, fact-based problem-solvers. This focus serves us well when we are tackling difficult technical problems and developing and executing process improvements. However, the need to cover so many technical areas in a chemical engineering curriculum often leaves little time for some of the “liberal arts” side of education, such as communication, psychology, writing skills and more. As chemical engineering students, we have enough challenges with kinetics, thermodynamics, fluid dynamics and process laboratory courses (Fig-

ure 1). So many of us enter the work world with a good technical foundation, but often with some skill gaps that we are not fully aware of yet.

After all, awareness and effectiveness in some of these “soft skills” are crucial for personal and professional success. These include additional topics, like understanding personalities, identifying one’s strengths and weaknesses, communication skills, practicing emotional intelligence, mindsets and behaviors and effective change management. I consider these “foundational skills” and have found that young and mid-career engineers find this “new” information fascinating as they navigate their own personal growth plans. Many have not taken the time to sit back

and consider that these skills can be learned and improved. The ones that do can develop advantages that help them both professionally and personally.

Rising up

In my years in operations, research and development, supply chain and business leadership, I have seen countless new engineers enter the workforce. Some have risen through the ranks of the workplace — distinguishing themselves as chemical engi-

neering professors, plant managers, business leaders and even CEOs of *Fortune* 500 companies — while others have failed to live up to their potential. In fact, some of my former coworkers have been let go due to performance, as well as personal issues. But why? Could this have been prevented?

To answer this, we must determine some of the common predictors of success. In my 40-plus years of experience, I have concluded that people who take their personal development seriously and have a (documented) plan that they follow with discipline do have an edge. Of course, technical competence is a fundamental element that must first be in place. Fortunately, several mentors shared this with me early in my career and I am forever indebted to them. It’s something I’m trying to pass on to the next generation of engineers.

If you work for a large company or institution, as I did, your human resources department likely has a targeted development planning process. Although these plans are often effective, they may not fully account for an individual’s holistic development and growth. The plans are often generated once per year and only reviewed occasionally throughout the year. (Note: many smaller companies do not have this formal process, so engineers need to develop their own development strategies and elements. Not sure where to start? Keep reading.).

As a manager of engineers for most of my career, I was responsible for helping develop these plans (for myself and others). They often focused on broad topics, such as business expertise, customer relationships and “getting results.” Al-



FIGURE 1. The need to cover so many technical areas in a chemical engineering curriculum often leaves little time for some of the “liberal arts” side of education

though they included other important areas, like influence, negotiation skills, planning, organizing and networking, it was often a challenge to develop specific action items beyond courses and one-on-one mentoring. After all, as humans, it's often difficult to gauge our own blind spots, gaps and personal strengths that could be leveraged or improved to gain the most benefit. This is where an effective 360-degree feedback process can be very useful.

When I had direct reports that took this process seriously, and worked to apply their newly acquired knowledge and skills to their roles, these reports tended to be the ones who rose to the top of their peer group and scaled the corporate ladder (both in technical- and business-progression ladders). This, in the beginning of my career (pre-Internet), meant reading a few books and magazines (such as *Harvard Business Review*) and receiving one-on-one mentoring and coaching. Fortunately, today, there is an abundance of resources available — including books, YouTube videos, LinkedIn resources, TED Talks, podcasts and more. So much so, in fact, that the sheer volume of personal development tools can be overwhelming.

This is in part why a documented personal development plan keeps us on track. A plan, along with a good “develop in your current role” strategy, has proven to be a comprehensive way of building a career and growth trajectory. In reality, you are both “competing” with peers, but more importantly, “competing” with becoming the best you. We all have had stages in our career where we have been so busy with work that we did not focus as much as we may have liked on our longer-term development and personal growth. Achieving this balance is possible and certainly desirable.

Carl Rentschler, an engineer like me who has been in the industry for many years, had similar advice in an article [1], in which he touted the importance of communication skills and networking. Of course, he assumed that technical competence was a base to start from. He wrote, “The level of competition within the engineering field will continue and

is likely to intensify.” I could not agree more — and one way for engineers to build a unique, personal advantage is to cultivate these foundational skills, in addition to advancing their technical skills. Have you ever thought of your own personal skillset in this way?

Where to start?

When coaching engineers or other individuals, I first work with them to determine their short- and longer-term goals, as well as the key areas they want to focus on most. Through multiple conversations, this often morphs a bit and boils down to two to three specific targets and development goals. We usually start with some of the foundational skills, such as personality-typing and strength-weakness assessments (there are numerous tools and tests), which help the individual better understand themselves and how others likely see them. From there, we tackle specific areas, including emotional intelligence, effective communication practices, practical negotiation skills, roadmapping and leading change, managing and leadership practices, becoming a trusted advisor, and navigating the first two to three months in a new role. This is a partial listing of the topics that are of most interest in pursuing together. My goal is to find one or two areas to target that the individual has high energy in focusing on.

Personality and strengths

I have often found that many early-career engineers are not aware of the helpful tools that are available to understand their own personality and areas of strength. Some have done personality profiles, but have not “mined the data” enough to dig a little deeper to understand the ramifications of what they have learned. Understanding personalities is important in life and helps each of us to understand the way we individually see things and the ways others see the same things. Some of us are more task-oriented and some of



FIGURE 2. To cultivate your foundational skills, try to pick only one or two key areas at a time to work on and remember the “SMART” process for your goals

us are more relationship-oriented. Some look first at the big picture and some dive right away into the details and analytics. There are many assessment tests available (for example, Myers-Briggs and DISC). Once an individual understands their personality type in more depth, they can also better determine and appreciate the personality types of their coworkers and managers, and tailor their communication strategies to their specific audience. This is not a form of manipulation at all. Each of us prefers to hear and process information in a certain way. A dominant personality, for instance, wants to get to the bottom line and options more quickly, while a cautious or compliant personality wants to know the details and understand all the facts before making a decision.

I have seen it first-hand many times. I remember vividly a situation where one engineer (a dominant) was presenting to his boss (a cautious/compliant) and did not review the details and facts to support his recommended solution. His boss was frustrated, but did not effectively explain his frustrations to the engineer. And it ultimately proved to be a career-killer for the engineer. He later left the company due to this and several other communication-related issues.

Understanding your top strengths is also an important element of your growth journey. Several good resources can help here, including “StrengthFinder 2.0” that has the CliftonStrengths assessment tool. In my past, performance reviews often focused on strengths and weak-



FIGURE 3. Learning to communicate effectively is a critical skill regardless of your personality type, and regardless of what your strengths and weak areas are

nesses equally, and often the discussions were more targeted on the weak areas. Many human resource professionals today believe that focusing on strengths is the higher priority, and I agree. Of course, weak areas that are career disruptors are crucial to identify and understand (and address). But if you are a 7 out of 10 in some strength areas that you can develop into an 8 or 9, these will help you stand out. But if you are a 3 out of 10 in a weak area, it might be difficult to raise it to anything above a 6. In your own development planning, you must determine if this weak area is worth the additional focused effort or not. If it is a significant gap area or even a career disruptor, then it should warrant some attention.

Support teams

To avoid the fate of this engineer and cultivate your foundational skills, I recommend that you develop your own “inner circle” of support for your growth. Your targeted development plan with your company, if you have one, is only part of this process. This includes finding a mentor or accountability partner to work with. It’s best that it not be your direct boss or anyone else on your direct work team, though they should have an active part of your personal growth plan. She or he should be chosen carefully and have the desire and time to invest in you for a routine one-on-one lunch or short meeting every few weeks or so. An effective mentor or coach will ask probing questions and help you to process areas that you are actively working on to improve your capabilities and skills and

on and remember the “SMART” process of having your growth goals specific, measurable, achievable, relevant and time-bound (Figure 2).

Working on foundational skills is something each engineer can and should be doing in a deliberate way, no matter our age and position in the workplace. But as one performance coach, Brendon Buchard, says, “the world cares less about your strengths and personality than about your service and meaningful contributions to others.” Results matter, but the way you get those results also matters. Are you a good listener? Do you allow others to make their points before injecting yours? Have you done your homework to be sure your proposals and recommendations are well thought out, and have you considered alternative approaches? Have you considered things from the other person’s point of view?

Communication skills

Learning to communicate effectively is a critical skill regardless of your personality type, and regardless of what your strengths and weak areas are (Figure 3). In his excellent book, “Everyone Communicates Few Connect,” leadership expert John Maxwell says, “It’s not enough just to work hard. It’s not enough to do a great job. To be successful, you need to learn how to really communicate with others.” A *Harvard Business Review* article agrees — “The number one criterion for advancement and promotion for professionals is an ability to communicate effectively.”

Do you look for opportunities to

improve your communication skills?

It is desirable to have several people in your organization, besides your direct supervisor, to discuss personal development with. Be selective, since unfortunately not everyone has the desire or mindset to support you in this process. Try to pick only one or two key areas at a time to work

improve your communication skills? This includes writing skills, as well as your speaking skills one-on-one, in small groups and in front of larger groups. I remember one engineer who was uncomfortable speaking in front of groups, and he decided that he wanted to work on this in a deliberate way. He joined a Toastmasters group to practice speaking in a comfortable setting where others were looking to do the same thing. He did improve and became a very effective presenter and communicator.

Robert Dilenschneider, a CEO, wrote about a “power triangle” that each of us creates around us that helps us be effective in our work and with others. He said, “The three components of this triangle are communication, recognition and influence. You start to communicate effectively. This leads to recognition and recognition in turn leads to influence.” As engineers, chemists, teachers and business leaders, we all can take the time and put in the effort to improve incrementally so that the cumulative effect is noticeable and beneficial to our careers.

You own the process

Each part of our career journey offers opportunity for delivering results and developmental growth. Personal growth can be an exciting, lifelong journey in which you can take a deliberate approach to pursue and achieve. If you do, I am confident it can accelerate your career and personal satisfaction — both at work and in your life away from work. ■

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1. Rentschler, Carl, *Career Guidelines for Young Engineers*, *Chemical Engineering*, January 2018, pp. 56–59.

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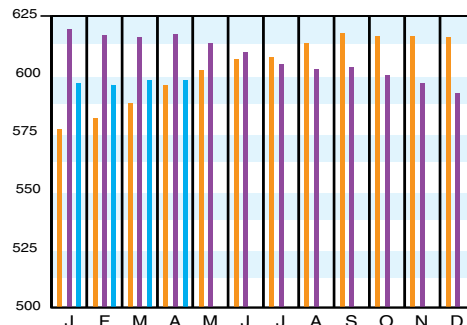
enterprise-wide continuous improvement programs. He now operates JGF Performance Consulting, LLC and focuses on coaching early and mid-career individuals. He has over 40 years of varied operational, supply chain, business, and consulting experience, primarily in the chemical and mining industries. He holds a B.S.Ch.E. from the University of Delaware.

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CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Apr. '20 Prelim.	Mar. '20 Final	Apr. '19 Final
CEIndex	595.5	598.3	617.3
Equipment	723.5	726.2	754.4
Heat exchangers & tanks	620.7	621.4	670.7
Process machinery	725.4	724.7	731.3
Pipe, valves & fittings	944.3	954.7	976.7
Process instruments	411.3	416.8	419.7
Pumps & compressors	1086.3	1085.2	1068.4
Electrical equipment	561.3	562.3	556.1
Structural supports & misc.	777.8	778.5	834.0
Construction labor	331.9	335.7	335.9
Buildings	590.7	595.2	598.3
Engineering & supervision	313.0	313.4	316.9

Annual Index:
 2012 = 584.6
 2013 = 567.3
 2014 = 576.1
 2015 = 556.8
 2016 = 541.7
 2017 = 567.5
 2018 = 603.1
 2019 = 607.5

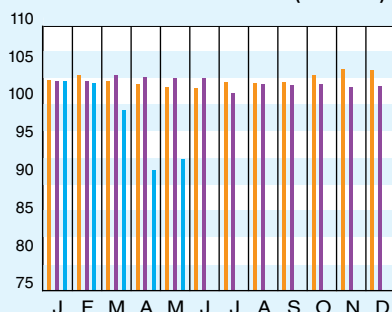


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76-77.)

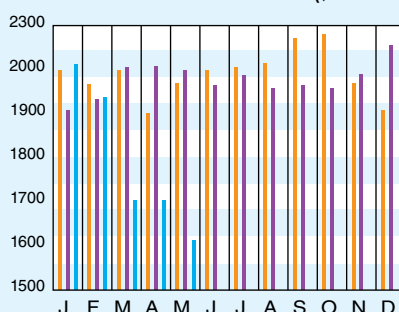
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS	YEAR AGO
CPI output index (2012 = 100)	May '20 = 90.7	Apr. '20 = 88.7	May '19 = 101.8
CPI value of output, \$ billions	Apr. '20 = 1,593.4	Mar. '20 = 1,809.5	Apr. '19 = 2,043.9
CPI operating rate, %	May '20 = 67.4	Apr. '20 = 66.1	May '19 = 76.1
Producer prices, industrial chemicals (1982 = 100)	May '20 = 203.1	Apr. '20 = 211.9	May '19 = 254.4
Industrial Production in Manufacturing (2012 = 100)*	May '20 = 87.2	Apr. '20 = 84.0	May '19 = 104.4
Hourly earnings index, chemical & allied products (1992 = 100)	May '20 = 183.7	Apr. '20 = 193.5	May '19 = 184.9
Productivity index, chemicals & allied products (1992 = 100)	May '20 = 97.3	Apr. '20 = 99.1	May '19 = 95.8

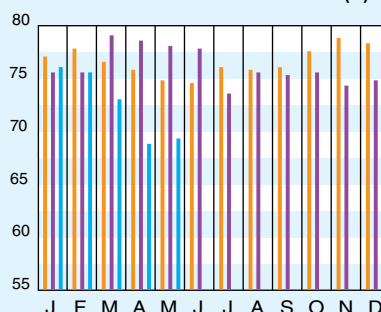
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE (\$ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.

†For the current month's CPI output index values, the base year was changed from 2000 to 2012

Current business indicators provided by Global Insight, Inc., Lexington, Mass.

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CURRENT TRENDS

The preliminary value for the CE Plant Cost Index (CEPCI; top) for April 2020 (the most recent available) decreased compared to the previous month's value, with the values of all four major subindices (Equipment; Construction Labor; Buildings; and Engineering & Supervision) comprising the CEPCI seeing declines. The current CEPCI value is 3.5% lower than the corresponding value from a year ago. Meanwhile, the Current Business Indicators (CBI; middle) showed a small rebound for the CPI output index and the CPI operating rate after declines in April. However, other measures, including the productivity index for chemicals and allied products decreased, as did the CPI value of output index for April.